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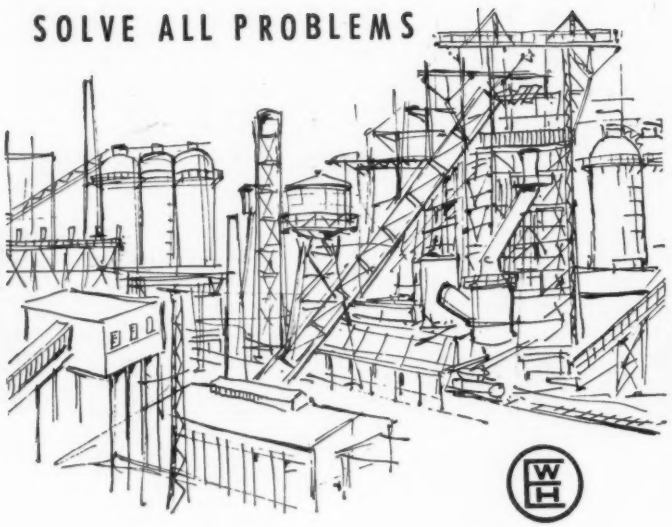

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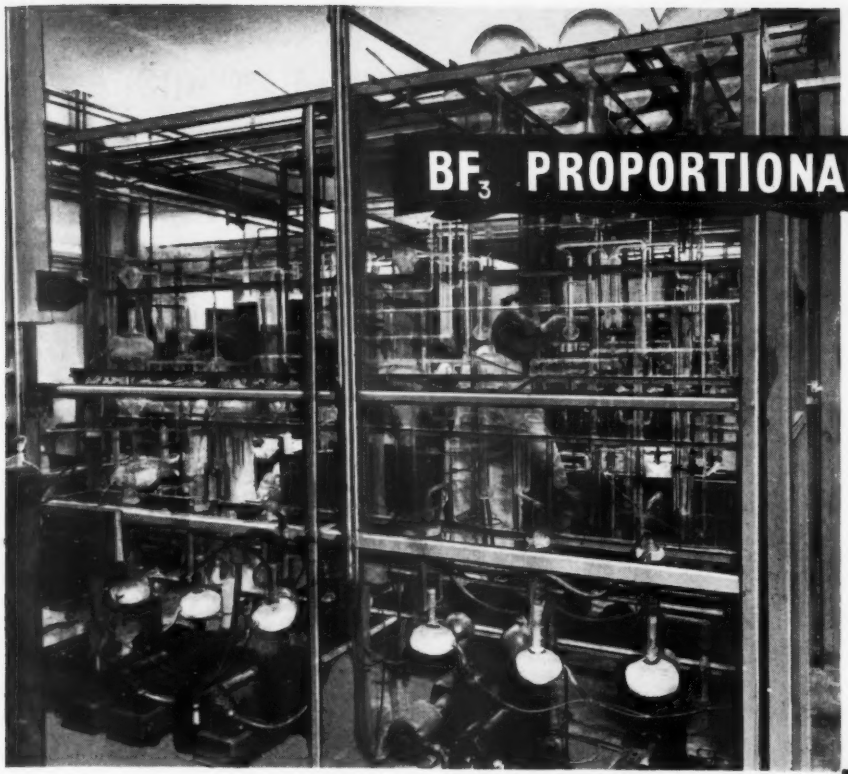

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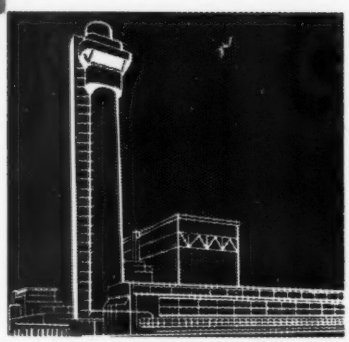

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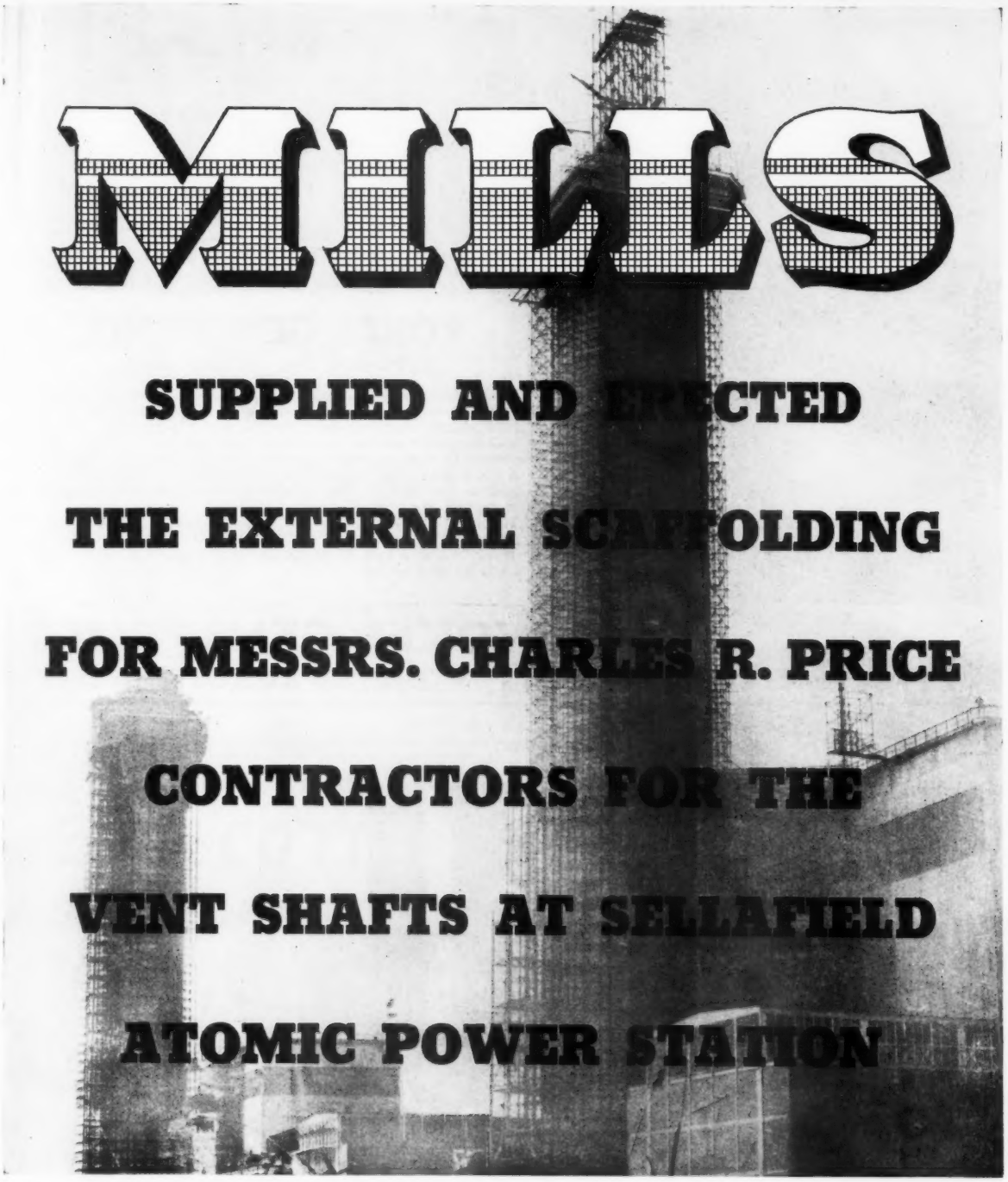


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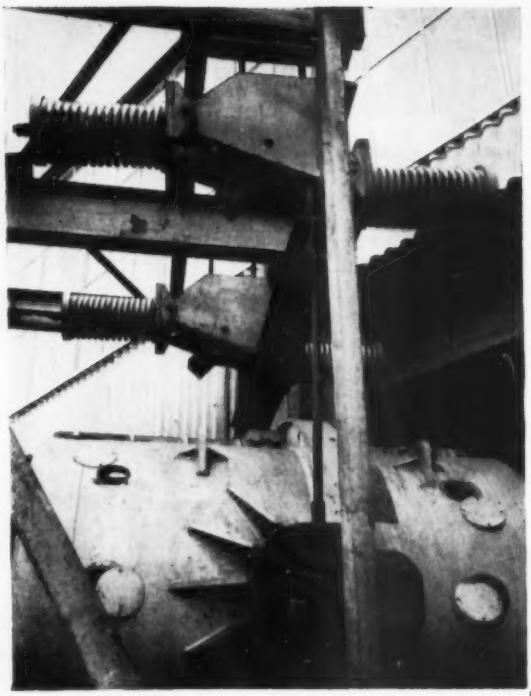

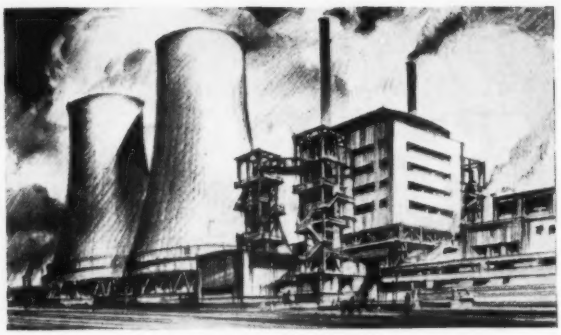

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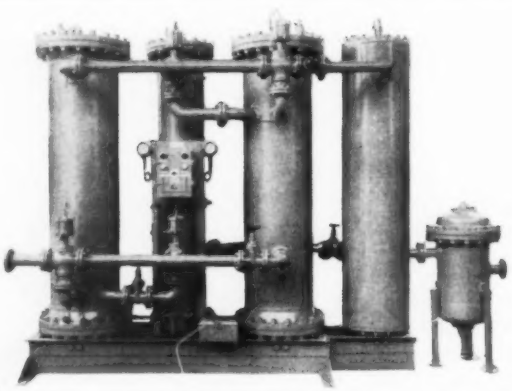

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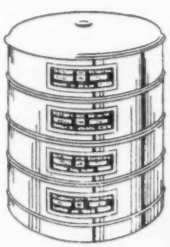

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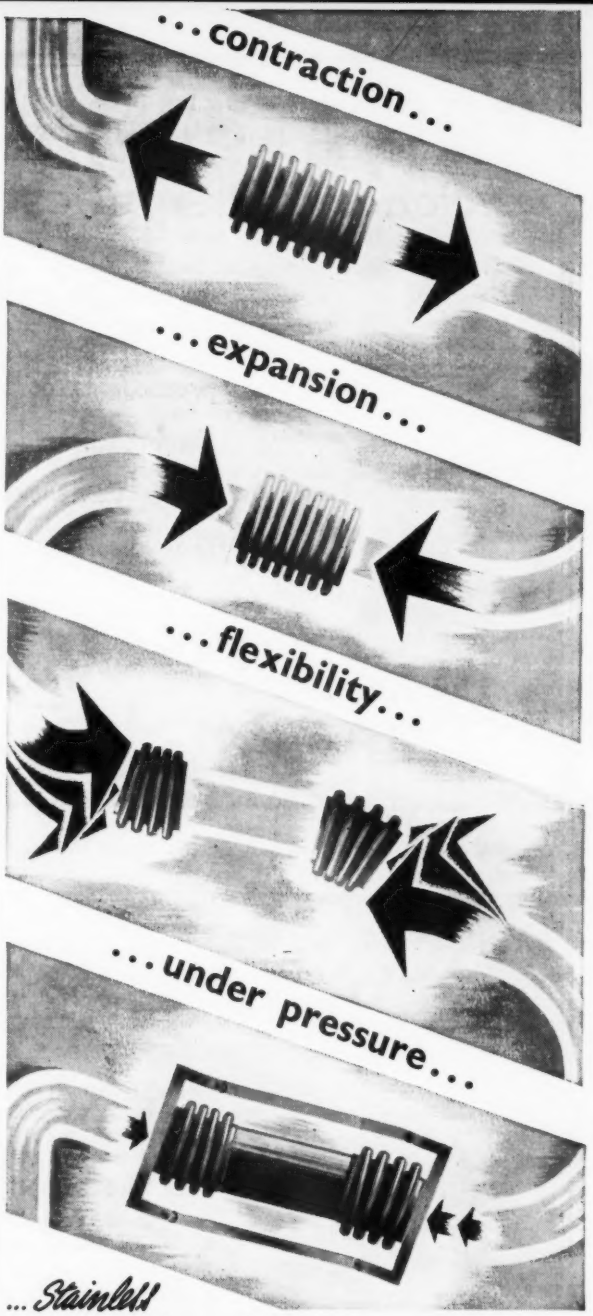


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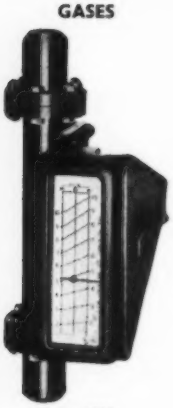

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Nuclear Power
AUGUST 1956 VOLUME I NUMBER IV

# Stocktaking

TO A WORLD TORTURED by an intolerable thirst for sensation, the second annual report of the United Kingdom Atomic Energy Authority will seem pretty small beer. But to those for whom food is more important than drink, it offers if not a meal at least a menu. In studying the report it is important to keep in mind its function; it is primarily a report to Parliament and the nation on how the Authority spent the £54m which was voted to it in the year 1955-6 and so is not for specialists. At the same time, it does succeed in giving what is presumably a very comprehensive overall picture of the Authority's main activities and plans in the non-military sphere and it never talks down to its readers. Of course it cannot give the whole picture and in particular we just have to accept the finances as a whole because the Operating Account is withheld on security grounds, the military side being inextricably mixed with the civil. Nevertheless, the tremendous security let-up which has been going on ever since Geneva—a relaxation which was vitally necessary if we were ever to get any power stations—has had its effect and the report is full of many interesting leads.

In the long term view, one of the most interesting passages is one dealing with fuel supplies and the Authority say they expect to be able to provide natural uranium fuel elements to match whatever volume of export orders may be secured in the foreseeable future. This is good but one wonders whether there will ever be a great demand for natural fuel in the countries to which we might export power reactors. Again, in the words "to match" there is perhaps a hint that we are not prepared to supply fuel without a reactor. This, if true, might eventually prove short-sighted.

In another part of the report the Authority hold out strong hopes for the development of relatively small Stage 3 breeder reactors of about 10MW capacity. These would undoubtedly provide an attractive export proposition since for many countries a 200-300 MW power plant—the probable size of the CEA ones—would be far too large in their present state of development. Northern Ireland for instance, has postponed the building of a nuclear power plant for this precise reason: a 200MW station could carry its present base-load several times over and an outage, even a non-nuclear one, would have the gravest consequences. These small reactors would of course need enriched fuel and this is at present available only in research amounts. It is encouraging to read however that part of the Capenhurst output—and the plant has recently been extended—is to be set aside for export orders. The fuel side of our activities needs tackling with imagination for it is the key to export trade. The building of a reactor is now within the capabilities of many countries but enrichment and separation plants are not. For this reason, the communal establishment of these plants ranks very high on the agenda of both the OEEC nuclear group and Euratom. In these matters we have a long lead over other countries in Western Europe—a lead which has cost the British taxpayer dear—and it could be used to make Britain a primary producer of nuclear fuel in a manner roughly analogous to our position as Europe's coal merchant prior to 1914. All this, of course would be dependent on a satisfactory international agreement to ensure that it did not go into armaments.

A disappointment in the report is the Authority's weak position on heavy water. Last year's report was full of high hopes on the New Zealand geothermal scheme and the use of "spraypak" was going to halve the cost of a conventional bubble-cap distillation plant. Now its abandonment last January is curtly dismissed with the explanation that the original £2m figure was less than half that of a later, and presumably more accurate estimate. One would like a few more details of this curious episode because for an estimate of this size, realistic enough for a company flotation, to be out by a factor of two seems to imply either incorrect working data or some extremely shaky arithmetic. It would also be of interest to know how much was actually spent on this scheme before it was abandoned and what stage it had reached. The OEEC countries are now considering what appears to be a very similar scheme for Iceland and they believe it can produce heavy water competitive with the American. It is to be hoped that the Authority will give them the benefit of their experience in this dismal affair. 'Fortunately,' brightly concludes this section of the report, 'no difficulty is expected in obtaining from elsewhere all the heavy water required.' Quite so, but this is probably due only to the fact that our programme is planned so that comparatively little will be needed.

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### AEA reports great activity

Research to achieve an economic controlled thermonuclear reactor has been going on in Britain since 1948 according to the UKAEA's *2nd Annual Report* published in London on July 25 (HMSO 2s 6d). The report states that a temperature of 100 million °C is necessary to make a fusion reactor possible and, while it is possible to initiate a fusion reaction at much lower temperatures, it is not certain that such a reactor can be built which yields more power than it consumes. The fuel used would be a mixture of deuterium and tritium, the latter being made by neutrons from the D-T reaction occurring in a lithium blanket. "Extremely high" temperatures have been achieved in laboratory experiments but many problems, says the report, have yet to be solved. Co-operation of universities and industry in this work is acknowledged.

The report confirms that, for the British stage 2 programme, the pressurized-water and the sodium-graphite reactor are the most likely contenders with a strong suggestion that the latter will be the final choice. Design studies and experiments on both are proceeding and a zero energy S-G system is under construction. Design of a reactor experiment is expected to commence this year. On stage 3 reactors, four systems—fast reactor, homogeneous - aqueous, liquid - metal fuel and high temperature gas systems are all under active consideration and it was revealed that the Hawker-Siddeley Nuclear Power Co Ltd are studying the LMFR. It is probable, says the report, that one or two of these systems will proceed to a reactor experiment in 1957-8. This would be a fairly small plant with an output of about 10 MW electricity and the Authority believe that such power plants would be more suitable for export than the larger stage 1 types.

The report states that the Authority will be responsible for supplying the necessary fuel for export reactors and says they expect to be able to provide natural uranium fuel elements to match whatever volume of export business may be secured in the forseeable future. Enriched fuel, it continues, is in short supply but part of the Capenhurst diffusion plant —which has recently been enlarged—has been set aside to provide fuel for export. According to AEA chairman Sir Edwin Plowden, however, this is likely to be only in kilogramme amounts.

No less than 21 reactors are now in operation, under construction or planned by the Authority alone —in addition to the CEA plans for 12 reactors.

The year under review—April 1, 1955-March 31, 1956—was one of great increase in interest and activity. A year ago, says the report, nuclear power appeared for most countries to be a possibility in the remote and indefinite future; now, it is a matter not of conjecture but of dates and comparative costs.

### Bradwell and Berkeley approved

Last month the Minister of Fuel and Power, Mr Aubrey Jones, gave permission for the building of the first two nuclear power stations of the Central Electricity Authority's 10-year plan for twelve stations. These will be on the sea coast at Bradwell in Essex and at Berkeley on the Severn Estuary in Gloucestershire.

Both of these stations will have two gas-cooled graphite-moderated reactors generally similar to the AEA's first station to be opened by the Queen on October 17th. They will be much more powerful however and the Minister's permission is for a total output of 200 MW from each station instead of the 93 MW from Calder Hall. It is understood that the nuclear side will not be much larger than the Calder Hall plant, the improvement in performance coming almost entirely from the striking adances in technology achieved since the Calder Hall station was designed.

Competitive tenders from the four large British groups — The Nuclear Power Plant Co Ltd, The AEI-John Thompson Nuclear Energy Co Ltd, the English Electric-Babcock and Wilcox Group and the GEC-Simon Carves Group—are due to be received for these stations by the CEA in October and it is expected that an announcement of the successful tenders will be made in January. Meanwhile preliminary site work at both locations is proceeding so that there will be no delay.

Following local fears expressed at the 4½ day enquiry held on the Bradwell station, regarding the local oyster fishery, the Authority say they intend to keep the problem under constant review and are to cooperate with the Ministry of Agriculture, Fisheries and Food in a continuing study of conditions in the Blackwater estuary.

Commenting later on the Berkeley proposal, President of the Royal Academy Sir Albert Richardson described it as one of the greatest acts of vandalism of the age. "Is it possible," he said, "that this miserable contraption should be planted here bringing in its train a mass of rubbish? This place is the very soul of England."

### No A-power for Ulster yet

Northern Ireland is not to embark on a nuclear power programme until well into the 1960's according to a NI Government White Paper (Cmd 355)—*Electricity in Northern Ireland*—published in Belfast last month. This reviews the question of Ulster Power supplies, past, present and future.

On atomic power the Government says that at one time it was thought that the forecasted increased demand for power might be met by a nuclear station about 1960 but further studies had shown that it would not be possible. The base load in the six counties is at present only 60 MW and since economic nuclear power stations are likely to be at least 200 MW it would not provide economical working. Furthermore, an atomic station would represent such a large proportion of the installed capacity that even a temporary outage would have a serious effect on supplies. Furthermore, the electricity undertakings have not at present the organization necessary

to look after the design and development work.

Nevertheless, it is visualized that atomic power will come and the White Paper assumes that a nuclear power station developing about 200 MW might be set up by 1964 and expanded during the next two years. At that time the maximum system demand is expected to be about 700-800 MW (at present it is about 370 MW).

The Electricity Board are meanwhile making preliminary plans and arrangements through their consultant, Kennedy and Donkin of London, and the Ministry of Commerce have sent a young engineer on a training course so that he may be available to the board when the time is appropriate.

## MERLIN for Weapons Group

Reactors for military purposes as distinct from actual weapons are now to be developed by the Atomic Weapons Research Establishment, under Sir William Penney. This is the significance of a paragraph in the UKAEA's *2nd Annual Report*. Simultaneously with its publication, the AEA announced that they had placed a contract with the AEI-John Thompson Nuclear Energy Co Ltd for a 5 MW light water reactor for the AWRE at Aldermaston.

The reactor, on which discussions have been taking place for the last six months, is fundamentally the same as MERLIN being built by AEI-JT for their own use (NUCLEAR POWER May) but special experimental facilities will be provided to suit the AWRE's special requirements: cooling will be by air-blast coolers in the primary circuit. Delivery is expected within twelve months.

The reactor, says the AEA statement, will be used "to obtain fundamental data required in the fields of weapon development and reactors for military purposes."

## AEA patents for Industry

The UKAEA is to bring to the notice of industry many of the developments and inventions which have arisen out of the work of its Research and Industrial Groups. The Authority now has a substantial holding of patents and patent applications which may be useful not only in the development of nuclear power but also for more general purposes.

A staff of Patent Officers attached to the Atomic Energy Establishment and the Industrial Group works closely with the scientists and engineers in assessing the value of inventions and taking appropriate action to patent them. In filing details they also give indications of the uses which might be made of the inventions in other industries. Mr Thomas Benson Gyles has been appointed by the Authority to act as a liaison officer with industry, and to advise on the uses to which these inventions might be applied and the terms (on a non-exclusive basis) under which they can be used.

Mr Benson Gyles, aged 52, although a member of a St Ives family, was born in Australia, and graduated at Melbourne University. He was with the Imperial Smelting Group for nineteen years, was a member of the Control Commission in Germany for seven years, and from 1952 until 1955 was General Superintendent of the Sindri Fertilisers and Chemicals, Ltd in India, where he also acted as a United Nations Consultant on the organization of nationalized enterprises in Asia working with other international representatives.

## Scotland's first power plant

The South of Scotland Electricity Board are to build a nuclear power station—probably on the Ayrshire coast—at a cost of about £35 m. The station will be of the gas-cooled graphite moderated type, similar to those being built for the CEA but the installed capacity is believed to be between 250 and 300 MW. There will be two reactors and the first one is due for commissioning in 1961, the second one in 1962. A coastal location is being chosen to simplify the circulating water problem.

Specifications have already been issued to four contracting groups and tenders are expected by next spring.

# belgium

## Belgian/US agreement

Belgium is to receive 8 Kg of uranium enriched up to 90 per cent $U^{235}$ from the United States under an agreement recently signed in Washington, the terms of which were published in Brussels on July 12th. The agreement will also give Belgium extra classified information and allows her to re-process irradiated fuel subject to approval of the plant by the AEC. The information agreement covers techniques for the extraction and preparation of uranium and thorium but not enrichment or isotope separation. The enriched fuel is for the new Belgian high-flux materials-testing reactor at Mol.

An interesting feature of the agreement is a provision that Belgium may transfer her rights to an "integrated group of nations." This might mean that the information could be passed to Euratom if it came into being, thus implying tacit US approval of that plan.

## Euratom discusses diffusion

Just after the OEEC meeting in Paris, the Euratom powers in Brussels were covering much the same ground in a different way. The inter-governmental committee heard M. Faure promise that while France is to make an atomic bomb she will not explode it for four years after the signature of the Euratom treaty. It now appears that Euratom will allow the use of fuel for military purposes—unlike the OEEC plan which does not. Its military use will however, be supervised by a security organisation to be set up.

It was agreed at the meeting that plans for the isotope separation plant should be pushed on but the exact position is obscure since the announcement recently of a new German process. Details of this have not been released but although it is not radically different from the gaseous diffusion process used in Britain and America, it should be much cheaper.

It is expected that the final Euratom treaty should be in draft form in about four months.

# france

## Britain cool on OEEC plan

Further steps towards the setting up of a European atomic organisation were taken at the meeting of the OEEC Council of

Ministers in Paris on July 18th. The Council had before it the report of a working party which was published in January and which had since been studied by a special committee. It was decided, in view of the committee's report, to set up a steering committee for nuclear energy composed of representatives of interested member countries together with the United States and Canada. The steering committee was charged with the job of preparing within a six months a draft statute for the future European Nuclear Energy Agency and then to submit it to the Council of Ministers.

The proposals of the working party fall under four general heads: joint undertakings; security control; international trade; and legislation, training and standardisation. The joint undertakings under consideration include: a uranium isotope separation plant; a chemical processing plant for irradiated fuels; a heavy water plant and high flux materials testing reactors. It is believed that the construction of a diffusion plant is quite feasible and preliminary estimates mention one handling 500 tons of uranium a year to produce from 1 to 1½ tons of $U^{235}$. No difficulty is seen about producing the uranium hexafluoride, and if the membranes are nickel this could be supplied from European sources. The great number of compressors needed however, might be a bottleneck and difficulties in recruiting sufficient technical staff are anticipated.

The chemical separation plant would handle about 500 tons of irradiated uranium a year and would probably use the solvent extraction method. On heavy water production, the working party state that Norway's production is now more than 18 tons a year and their report mentioned as likely that the principal American method is the hydrogen sulphide-water dual temperature exchange system. No very definite proposals were made on this problem but it is stated that geothermal steam in Iceland would allow the production of some thousands of tons a year at economic cost provided corrosion problems could be overcome.

Britain's position regarding OEEC was clarified somewhat when it was announced by Sir Edward Boyle, Economic Secretary to the Treasury, that she would probably cooperate in a chemical separation plant but not in the other projects. Even on this it was not certain that she would extend the cooperation to the actual construction, but would limit her share to technical advice.

## germany

### Cabinet passes nuclear Bill

Last month two Bills were approved by the Federal Cabinet in Bonn which will have the effect of settling the West German atomic energy programme. The Bills are the work of Franz Josef Strauss's Ministry for Atomic Affairs and have still to pass the Bundestag when it reassembles after the summer recess.

The proposed laws will provide the minimum of State intervention in atomic energy and private enterprise would be given the widest scope. The import and export of fissionable material, however its transport and handling would be under strict State control. The proposals would definitely exclude any military applications: if Germany eventually had nuclear weapons they would come under the control of the Ministry of Defence.

Present plans include the building of a reactor in Karlsruhe, partly financed by the Baden-Württemberg *Land* Government and industry, and smaller research reactors in Munich, Frankfurt, Cologne, Hamburg and Berlin. Uranium deposits, too, will be exploited and workings in the Fichtelgebirge are said to be already yielding fair quantities of ore. During the current year an expenditure of 45m DM has been authorized.

It was announced in New York on June 22nd that AMF Atomics Inc. had obtained a contract for the Munich reactor which is to be at the Technische Hochschule.

An agreement with Britain was signed by Herr Strauss in London last month which provides for material supplies and technical aid. It has already been announced that Germany is to buy a MERLIN reactor from AEI-John Thompson and that she will probably also obtain a DIDO from Head Wrightson Processes at a cost of £2m. Another contract which is under discussion is one for a 15 MW power reactor to be supplied jointly by AMF in America and Mitchell Engineering Ltd in London.

## italy

### Professors' five-year plan

Italy's nuclear power programme which has so far received very little official support is apparently in low water and last month Prof. Giordani, the chairman of the National Committee for Nuclear Research, resigned. The official reason for the professor's resignation was given as poor health. During the last four years the committee have only received £2m from the Government and now a group of five leading physicists, led by Prof. Amaldi, have put forward a five-year plan to Prime Minister Segni proposing that £57m should be spent during the period.

Meanwhile private industry has not been inactive and the Fiat car company and the Montecatini chemical combine have formed a joint company known as Sorin for atomic power developments.

## far east

### Asian countries confer

A two-day conference on the peaceful uses of atomic energy was held in Bombay last month under the aegis of Indian Atomic Energy Commission chairman Dr Homi J. Bhabha. The delegates were drawn from India, Burma, Ceylon, Egypt and Indonesia and it was agreed that similar conference should be held regularly and extended to cover other Asian and African countries.

## middle east

Egypt is to receive aid in nuclear research and power utilisation from the Soviet Union under the terms of an agreement signed in Cairo on July 12th by Atomic Commission chairman Kamal eddin Hussein and Soviet ambassador

E. D. Kisilev. Under the terms of the agreement, Egypt will send specialists for training to the USSR and the two countries will also conduct joint researches. In Cairo a nuclear physics laboratory is to be built with Russian aid and this will include a 3 MeV particle accelerator and a 200 kW experimental reactor. These laboratories will be completed in 1958. The agreements will be accompanied by trade treaties.

## scandinavia

### Danes to have US reactor

The Danish Atomic Energy Commission is planning a research centre on a peninsula near Roskilde, about 20 miles west of Copenhagen. A research reactor costing about $1·4m is being obtained from the United States with the aid of a $350,000 grant from the Eisenhower atoms-for-peace plan. The reactor will be a swimming-pool type and is to be designed and constructed by the Foster Wheeler Corporation of New York. Assembly and installation at site will be aided by Danish firms. Two Danish scientists are at present studying at the Argonne's International School of Nuclear Science and Engineering while another has had six months at Brookhaven.

## soviet union

### Synchrophasotron for JINR

The text was released in Moscow last month of the agreement setting up the 11-nation Joint Institute of Nuclear Research signed in Moscow on March 26th (NUCLEAR POWER June). The agreement has ten articles and sets out the aims, objects and organization of the Joint Institute. Article IV confirms that the Nuclear Problems Institute of the Soviet Academy of Sciences has been handed over to the Joint Institute. This includes the 680 MeV proton synchrocyclotron and the 10 GeV synchrophasotron. To further work of the joint institute, further facilities are to be provided.

Each member of the Joint Institute contributes to the maintenance and shares were determined, ranging from 47·25 per cent for the USSR to 0·05 per cent for Albania, North Korea and Mongolia.

Speaking in the Supreme Soviet on July 16th, Foreign Minister D. T. Shepilov made another appeal to the West for the banning of atomic weapons and invited western countries to join in the work of the Joint Institute. He also suggested a new all-Europe atoms-for-peace conference. Western observers remark that this was presumably an attempt to prevent the OEEC and Euratom plans from going through.

## united states

### Feet dragging in Washington?

A Bill authorizing a $400m programme for building four government nuclear power stations passed the Senate by a narrow majority on July 13, but in the House it failed to clear the rules procedure which makes it unlikely that it will be heard before Congress rises. The Bill had a threefold purpose—1. to allow the AEC to build large-scale prototype stations and use the power produced for their own production facilities, 2. the development of reactor designs and construction under private contract of small advanced reactors, 3. expansion of the project programme of cooperation with other countries.

The Bill arose out of a five-day hearing in May of Senator Anderson's Joint Congressional Committee on Atomic Energy. The House Appropriations Committee, which energetically supported the measure, strongly criticised Admiral Strauss and the AEC for their opposition to it and claimed that they were thwarting President Eisenhower's "Atoms for Peace" plan in the interests of private industry. Fears have been expressed in Washington circles that the United States would lose out to Britain and Russia if it continued to withhold Government funds for prototype power plants.

### CP-5 reactor for MIT

The Massachusetts Institute of Technology has received AEC permission to build a heavy-water moderated and cooled research reactor. The maximum power level will be 1,000 kW and the reactor will be based on the Argonne National Laboratory's CP-5. It will be built for MIT by ACF Industries of New York and will be contained in a 70 ft diameter, 50 ft high steel pressure shell.

The AEC have now issued seven licences for the construction or operation of research reactors. The others are: the Armour Research Foundation, The Battelle Memorial Institute, the Naval Research Laboratory, North Carolina State College, Pennsylvania State University and the University of Michigan.

### Ore production tops 3m tons

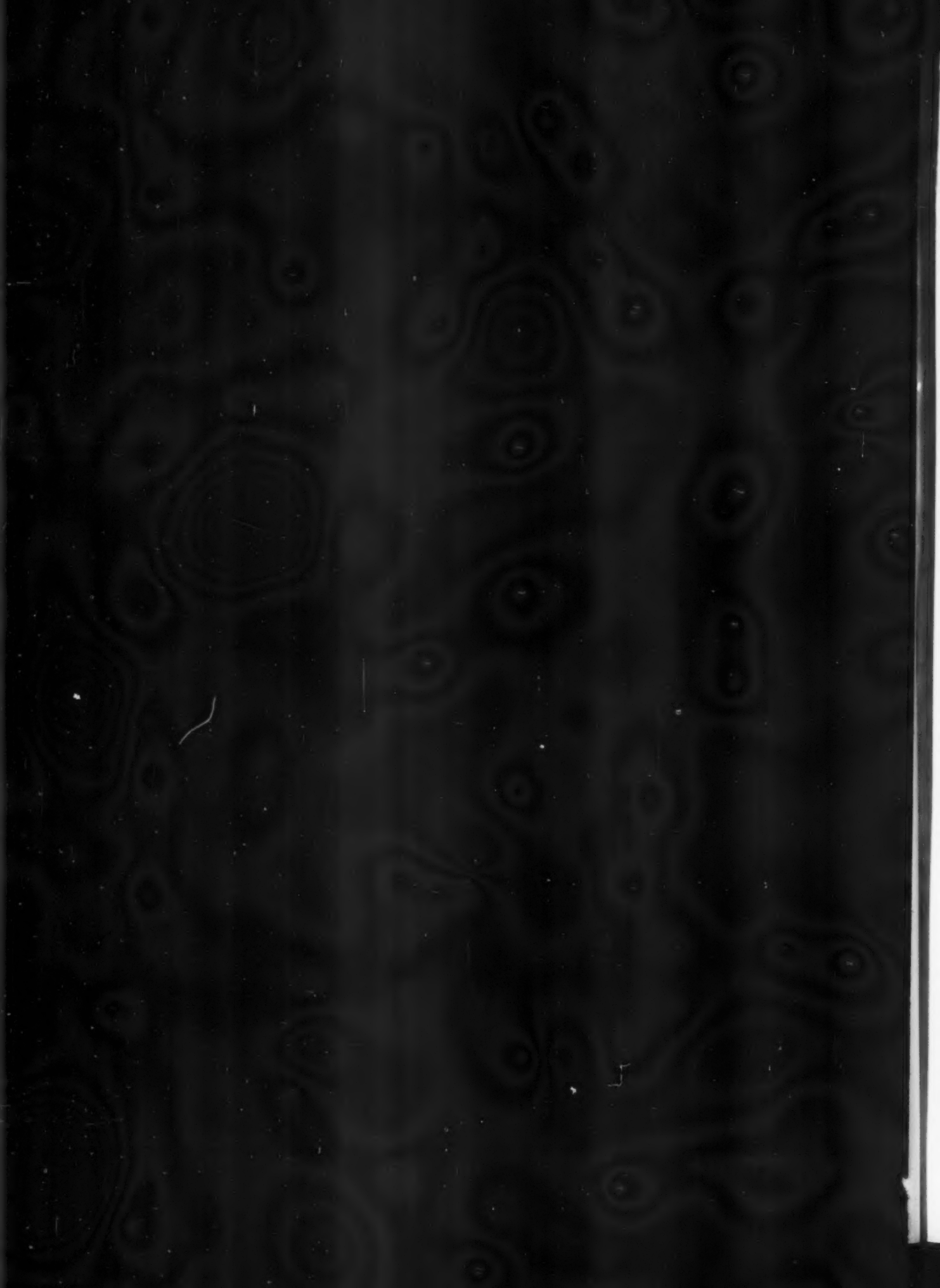
The United States is mining uranium ore at a current annual rate of nearly three million tons, according to Jesse C. Johnson, Director of the Division of Raw Materials, US Atomic Energy Commission, speaking in Washington on June 25. This contrasts with only 70,000 tons mined in 1948, a year after the AEC was organized, he said in an address to a meeting co-sponsored by the Atomic Industrial Forum, Inc, and the Research Institute of the University of Denver.

Mr Johnson said "atomic energy for industrial power has become a reality. The problem now is to make it more competitive by developing more efficient reactors."

"Not only are the defence requirements being met," he continued, "but the development of atomic power for industrial use has been greatly advanced."

When the atomic energy programme was initiated in 1948, known ore reserves were about one million tons; today they are in excess of 30 million tons. Potential reserves are estimated at about another 30 million tons.

Despite the large expansion schemes under way in Canada and South Africa, Mr Johnson said domestic production during the next five years will continue to provide a large portion of the US total uranium supply. "Beyond that period," he said, "our position as a world producer will depend largely upon the domestic and foreign developments and upon the world market for uranium."



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***A simpler and cheaper way of removing fission products from irradiated fuel elements would prove of inestimable value. Recent work at Harwell shows considerable promise***

# Zone melting of uranium

THE TECHNIQUE of zone melting was developed by the electrical industry for the purification of germanium and silicon. It consists in passing a bar of the metal to be purified slowly through a resistance furnace or induction coil, in such a manner that a molten zone is formed and made to traverse the length of the bar. The principle of the purification can be understood by considering phase diagrams; if, as is usually the case, the impurities lower the melting point of the pure metal they will concentrate in the molten zone and be deposited at the end of the bar, leaving the major part of the bar purified. The impurities that raise the melting point of the solvent concentrate at the opposite end of the bar. The purification will be greater, the greater the difference in solubility of the impurities in the solid and liquid phases.

As a molten zone advances an impurity concentration gradient is built up within the zone. If the impurities lower the melting point of the solvent they will concentrate in the liquid next to the interface from which they may be removed by diffusion and convection; the more efficiently this is done, the greater the purification. As uranium is considerably denser than most elements it was considered that density differences might be used to lower the concentration gradient and increase the separation. To investigate this possibility a vertical apparatus was adopted.

Two types of solutes have been investigated, metallics and non-metallics; they have been considered separately because the metallics move essentially by a zone melting process whilst the non-metallics move by a modified flotation process.

### Experimental method and results

A vacuum molybdenum tube resistance furnace (Fig. 1) was used for these experiments. The heating tube was 0·005 in. thick, 1 in. in diameter and 2 in. long. Tantalum radiation shields $\frac{3}{4}$ in. long surrounded the heating tube. When at temperature, the furnace needed approximately 600 amps. The uranium used was calcium-reduced material; typical impurities were: iron 200 ppm, aluminium 100 ppm, silicon 100 ppm, oxygen 100 ppm, and carbon 700 ppm. The bars were $\frac{1}{4}$-$\frac{3}{8}$ in. diameter, 4-5 in. long and contained in beryllia crucibles. The molten zone was approximately $1\frac{1}{2}$ in. long, the temperature at its centre being 1150-1300°C. This temperature is necessarily approximate and was deduced from separate power calibration experiments in which a thermocouple was suspended in a crucible containing no uranium. The vacuum was obtained by an Edwards oil diffusion pump and backing pump and was better than 0·01 microns.

A disadvantage of the apparatus was the beryllia

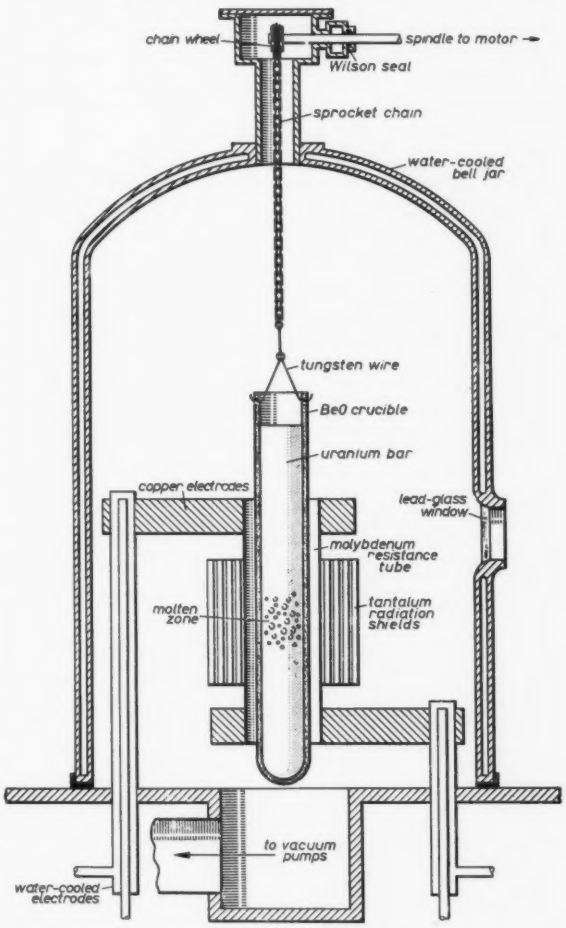


**Fig. 1** ***a schematic section of the vacuum molybdenum resistance furnace used in these experiments. The uranium bar of $\frac{1}{4}$ in. to $\frac{3}{8}$ in. diameter is contained in a beryllia crucible which is slowly raised and lowered past the heated zone***

*ZONE MELTING EXPERIMENTS in a vertical furnace have shown that to remove soluble metallic elements from uranium slow zone speeds (½ in./hr) are necessary and density differences may be harnessed to increase the purification. The non-metallic elements carbon and oxygen may be removed at much faster zone speeds (3 ins/hr).*

*Zone melting has been considered as a modified self-slagging process for the removal of fission products from irradiated uranium. Greater decontaminations for zirconium and for total activity were obtained than in self-slagging experiments. A certain minimum concentration of carbon and oxygen is necessary to obtain the maximum elimination of fission products.*

*LES EXPÉRIENCES RELATIVES à la fusion zonale dans un four vertical montrent que de petites vélocités zonales (6,4 mm/h) sont nécessaires pour éliminer de l'uranium les éléments métalliques solubles et qu'il est possible d'utiliser les différences de densité pour améliorer la purification. Les métalloides carbone et oxygène peuvent être éliminés avec des vélocités beaucoup plus grandes (7,6 cm/h).*

*La fusion zonale est regardée comme une modification du procès de l'auto-scorification, développée pour éliminer les produits de fission de l'uranium irradié. On obtient par fusion zonale une réduction plus avancée de la proportion du zirconium et de la radioactivité totale que par les expériences d'auto-scorification. Une certaine concentration minima de carbone et d'oxygène est indispensable pour obtenir l'élimination maxima des produits de fission.*

*ZONENSCHMELZUNGSEXPERIMENTE in einem senkrechten Schmelzofen zeigen, dass zum Entfernen löslicher metallischer Elemente aus Uran kleine Zonengeschwindigkeiten (6,4 mm/h) benötigt werden und dass Dichteunterschiede zur Verbesserung der Reinigung herangezogen werden können. Die Nichtmetalle Kohlenstoff und Sauerstoff können bei viel grösseren Zonengeschwindigkeiten (7,6 cm/h) entfernt werden.*

*Zonenschmelzung wird als Abänderung des Selbstentschlackungsprozesses zur Entfernung von Spaltungsprodukten aus bestrahltem Uran betrachtet. Es wurden bessere Entfernungsausbeuten für Zirkonium und totale Radioaktivität erhalten als in den Selbstentschlackungsexperimenten. Ein gewisser minimaler Kohlenstoff- und Sauerstoffgehalt ist notwendig, um maximale Entfernung der Spaltungsprodukte zu erreichen.*

*PRUEBAS DE FUSIÓN DE ZONA en un horno vertical han demostrado que para la extracción de elementos metálicos solubles del uranio, se requieren velocidades de zona reducidas (6,4 mm/h), y las diferencias en densidad pueden utilizarse para aumentar la purificación. Los elementos no metálicos, carbono y oxígeno, pueden extraerse a velocidades de zona sumamente mayores (7,6 cm/h).*

*La fusión de zona es considerada como un proceso automático modificado de escorificación para la eliminación de productos de fisión del uranio irradiado. Resultaron mayores descontaminaciones de zirconio y de actividad total, que en pruebas de autoescorificación. Se requiere cierta concentración mínima de carbono y oxígeno para obtener la eliminación máxima de productos de fisión.*

*ОПЫТЫ ПО ЗОННОМУ плавлению в вертикальной печи показывают, что для удаления растворимых металлических элементов из урана нужны малые зонные скорости (6,4 мм/час) и что существует возможность использовать разности плотностей для улучшения очистки. Металлоидные элементы углерод и кислород можно удалять при гораздо бо́льших скоростях (7,6 см/час).*

*Зонное плавление рассматривается как видоизменение процесса самошлакования для удаления продуктов деления из облученного урана. В результате зонного плавления получилась лучшая очистка от циркония и полной радиоактивности нежели в опытах самошлакования. Некоторая минимальная концентрация углерода и кислорода нужна для получения максимального удаления продуктов деления.*

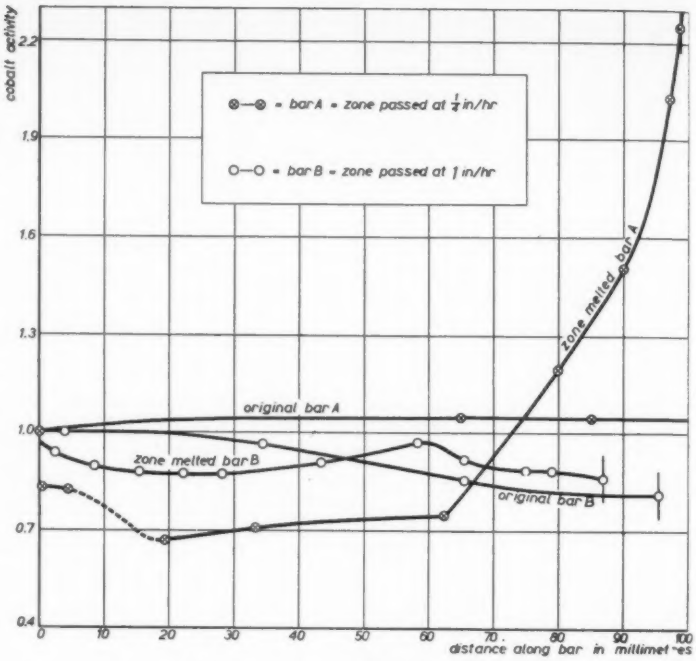


**Fig. 2** ***zone melting of uranium with cobalt present to 500 parts per million results in good separation at speeds below 1 inch per hour***

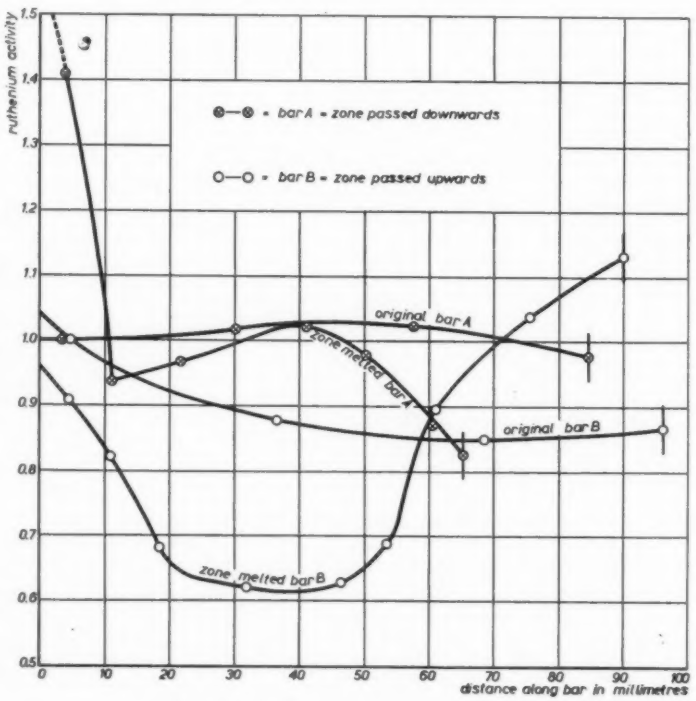


**Fig. 3** ***with uranium containing ruthenium to 800 parts per million, greater contamination was obtained when the zone was passed upward due to density effects***

crucible. A fresh crucible had to be used for each zone pass because the uranium cracked it upon cooling to room temperature; also the metal picked up 25 ppm beryllium with each pass.

### Metallic solutes

Two metallic solutes were studied, cobalt and ruthenium. As only small concentration changes were involved an accurate analysis technique was required to give the distribution along the bar rather than absolute values for the composition. Radioactive tracer techniques fulfilled the conditions and were adopted. Natural uranium itself is $\alpha$ active and in order to allow the uranium activity to be filtered out, the strong $\gamma$ emitters $Co^{60}$ and $Ru^{103}$ were used as tracers. After zone melting small transverse slices of the bars, cut $1 \pm 0{\cdot}2$ mm thick by a rubber-bonded carborundum wheel, were placed in a standard position under a geiger-müller end-window counter. 0·024 in. of lead was placed between the counter and sample to absorb the uranium activity. The absorption of the isotope activity by the uranium did not affect the results, and as good reproducibility was obtained no elaborate precautions were necessary to make the slices the same thickness.

The procedure consisted of first making a homogeneous alloy by melting a uranium bar with a known weight of the isotope, in the metallic form, in the zone melting furnace using a long molybdenum heating tube. The alloy was sectioned, analysed radiochemically for homogeneity and then zone melted and analysed again. The results after one zone pass are shown in Figs. 2 and 3. The length of the bar was measured from the bottom which is represented by the left-hand side of the diagrams. The length after zone melting was less than the original length because until the bar melted it was not the same shape as the crucible. For comparison, the activity at the bottom of the bar before zone melting has been made unity and corrections made for any decay.

The experiments on uranium containing 500 ppm cobalt (Fig. 2) in which the zone was passed upwards proved that to remove soluble metallic impurities a zone speed of less than 1 in/hr had to be used; a speed of $\frac{1}{4}$ in/hr gave good separations. The results for uranium containing 800 ppm ruthenium when the zone was passed upwards and downwards at $\frac{1}{4}$ in/hr are shown in Fig. 3. The greater decontamination obtained when the zone was passed upwards proves that even for soluble impurities at a low concentration density effects can be harnessed to advantage. Similar results have been obtained by North, for small amounts of silicon (800 ppm) and iron (400 ppm) in aluminium[1]. The separations obtained for cobalt and ruthenium and the fact that both elements concentrate in the molten zone are consistent with the available phase diagrams[2, 3].

When lowering the crucible the greatest purification for both cobalt and ruthenium was obtained in the centre of the bar. The bad separation in the bottom cannot be due to supercooling because of its extent and because the concentration curve is smooth; variation of zone length along the bar is probably the cause. A smaller molten zone would be expected in the centre of bar than at the ends due to heat losses by conduction, and therefore the solid-liquid interface when moving towards the centre travels faster than designed, resulting in bad purification. The effect was not obtained when the zone was passed downwards because the top of the bar was approximately 1-2 in. from the top of the crucible allowing heat to be conducted along the crucible.

### Non-Metallic solutes

The movement of the non-metallic elements carbon, oxygen and nitrogen present in natural uranium was studied passing the zone upwards. The results are summarised in Table I. Carbon was analysed by a combustion method and oxygen and nitrogen by vacuum fusion; reproducibility was good. It was not feasible to obtain concentration distributions due to the amount of analytical work involved, instead each of the treated bars was analysed approximately $1\frac{1}{2}$ in. from the bottom.

For experiments 1 and 6 (Table I) in which the bar was completely molten at some stage the maximum temperature was between 1150° and 1300°C.

| experiment number | treatment | carbon (ppm) | | oxygen (ppm) | | nitrogen (ppm) | |
|---|---|---|---|---|---|---|---|
| | | original | after treatment | original | after treatment | original | after treatment |
| 1 | whole bar held molten for 2 hours and then quenched | 720, 700 | 580, 590 | 150, 100<br>120, 100 | 30, 60<br>50, 50 | | |
| 2 | bar zone melted with zone speed of $\frac{1}{4}$ in/hr | 810, 820 | 900, 410<br>430 | 110, 110<br>110, 80 | 49, 80<br>50, 40 | 85, 90<br>30, 60 | 10, 10<br>6, 8 |
| 3 | as above | 690, 700 | 410, 415 | 170, 200<br>160, 190 | 76, 66<br>70, 63 | | |
| 4 | bar zone melted with a zone speed of 3 ins/hr | 810, 820 | 270, 260 | 110, 110<br>110, 80 | 30, 33<br>25, 23 | 85, 90<br>30, 60 | 8, 8<br>7, 5 |
| 5 | as above | 670 | 470 | | | | |
| 6 | bar completely melted and then lowered through furnace at $\frac{1}{4}$ in/hr | 690<br>700 | 365<br>410 | 170, 200<br>160, 190 | 33, 40<br>30, 58 | | |

**Table I** ***removal of non-metallics from uranium by zone melting***

Table I reveals that for carbon removal zone melting has an apparent advantage over straight flotation whilst no improvement is obtained for oxygen. In contrast to metallic solutes, the non-metallics separated with a zone speed of 3 in/hr and a speed of ¼ in/hr did not increase the separation, possibly due to contamination by the diffusion pump oil. An appreciable purification was also obtained for nitrogen with both speeds. A microscopic examination revealed that the non-metallic inclusions had coalesced (Fig. 7). This coalescence is connected with the mechanism of carbon removal and is discussed later in the paper.

### Zone melting of irradiated uranium

An obvious application of zone melting is the removal of fission products from irradiated material. Reactor fuels have to be processed at regular intervals for various reasons, one of which is the build up of fission products with a high neutron capture cross-section. The more important fission products include the rare earth metals, xenon, caesium, barium, strontium, zirconium, molybdenum and ruthenium. A self-slagging process has been developed which consists in melting and solidifying the metal[4] whereby the reactive fission products such as the rare earth metals become associated with the non-metallic impurities in uranium and concentrate in the skin of the ingot. Zone melting applied to irradiated material could therefore be considered a modified self-slagging process and the reactive fission products should behave in the same manner as oxygen and carbon.

Bars irradiated in a neutron flux of $2{\cdot}5 \times 10^{10}$ neutrons $cm^{-2}$ $sec^{-1}$ for 5 hours and cooled for 8 days have been zone melted passing the zone upwards at a speed of 3 in/hr. Individual fission product analyses were done for two bars and compared with typical decontaminations obtained in self-slagging experiments (Table II). Larger decontaminations were obtained for zirconium and smaller for cerium.

As zirconium carbide has a larger negative free energy of formation (Table III) than uranium carbide and urania is more stable than zirconia the zirconium would be associated with the carbon in the molten metal. The increased zirconium decontamination is therefore due to the efficient removal of carbon. The poor decontaminations obtained for cerium by zone melting are discussed later.

Analyses of the individual fission products are very lengthy and it was usual to measure only the total activity. The decontaminations normally obtained for $\gamma$ and $\beta\gamma$ activity in the centre of the bars were 80 per cent and 75 per cent respectively compared with 30-60 per cent and 75 per cent for material with a similar irradiation history in self-slagging experiments. It is difficult to compare the decontaminations for total activity with those for individual fission products in Table II because many fission products not considered individually contribute to the total activity. However, the increased $\gamma$ decontamination obtained by zone melting must be due in part to the more efficient removal of zirconium. The result for the total $\gamma$ activity able to penetrate 0·024 in. of

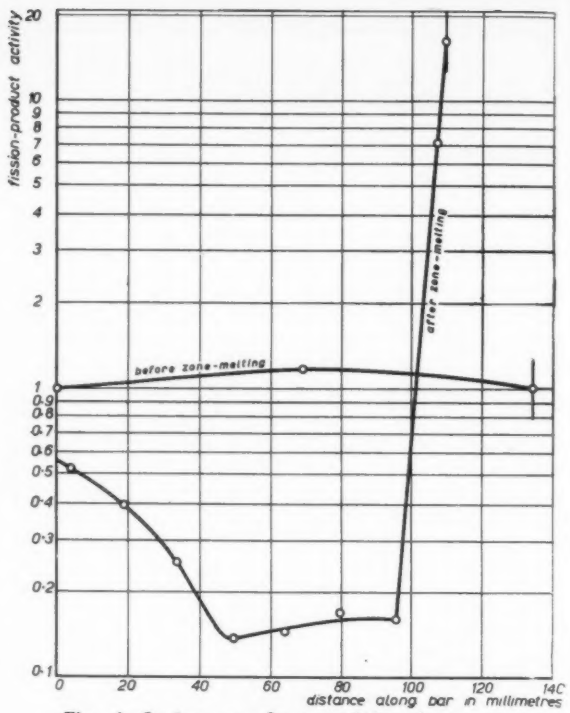


**Fig. 4** *fission product activity from an irradiated uranium bar zone-melted at a speed of 3 in./h*

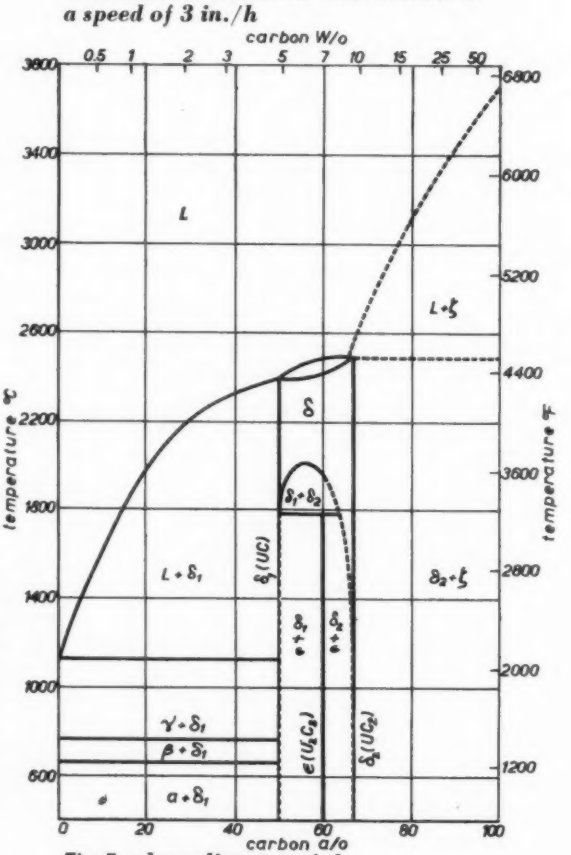


**Fig. 5** *phase-diagram of the uranium-carbon system*

lead, four days after zone melting is shown in Fig. 4. To determine whether the concentration of the non-metallic elements significantly influenced the removal of fission products, an irradiated bar was zone melted twice, a bar previously zone melted was irradiated and zone melted again and an irradiated bar was zone melted with the addition of 5,000 ppm carbon and 600 ppm oxygen. In the first experiment the decontamination did not increase with the second pass; in the second experiment the $\gamma$ and $\beta\gamma$ decontaminations in the centre of the bar were 50 per cent and 30 per cent and in the third 80 per cent and 75 per cent respectively. These results indicate that the uranium metal as received was satisfactory and there was no advantage in adding oxygen or carbon but if purified there was an insufficient quantity of non-metallic elements present to affect the maximum possible decontamination; in this connection oxygen was probably the most important as its concentration in zone melted material is only 30-60 ppm. These results apply for small uranium burn-ups ($10^{-3}$ MWD/T); a larger minimum concentration of non-metallics may be required for the larger burn-ups obtained in power reactors necessitating the addition of carbon and oxygen to material not previously treated.

The noble fission products such as ruthenium and molybdenum should be considered as soluble metallic elements and for their removal slow zone speeds would be required.

## Discussion

To obtain a significant reduction in the concentration of metallics, multiple zone pass experiments are necessary as less than 40 per cent of most of these impurities are removed in each pass. These could not be done in the present apparatus because a fresh crucible was required for each pass and because the metal became contaminated with beryllium. For such experiments two types of apparatus appear suitable, firstly a type developed by Keck[5] in which there is no crucible container and the zone is held in place by surface tension. Its feasibility has been demonstrated by moving a molten zone $\frac{1}{8}$ in. long, along a $\frac{1}{4}$ in. diameter uranium bar using induction heating and a concentrator. To increase the diameter of the bar or the length of the zone a certain amount of development work would be required because upon increasing the zone length gravity forces overcame surface tension and collapsed the zone. In a second type of apparatus suggested by Pfeil[6] a urania crucible is used and the solid metal either side of the zone is kept above the $\gamma$-$\beta$ transition temperature by auxiliary furnaces. $\gamma$ uranium is plastic and therefore there is little likelihood that the metal would crack the crucible, allowing multiple zone passes to be made.

That the segregation of the metallic solutes in uranium is very sensitive to zone speed is interesting when compared with the experience obtained zone melting germanium and silicon where speeds of 6 in/hr may be used[7]. Uranium is not the only element for which slow speeds must be used since similar results have been obtained for copper and zinc in aluminium[8] and iron, silicon, aluminium and man-

| fission product | zone melting | | self slagging [4] |
|---|---|---|---|
| | Expt. 1 | Expt. 2 | |
| Ce | 48 | 45 | >90 |
| Zr | 87 | 75 | 50 |
| Sr | 90 | 90 | >90 |
| Ru | 0 | 10 | 0 |
| Mo | 0 | – | 0 |

**Table II** ***percentage removal of fission products from uranium***

| compound | $-\Delta G^\circ$ |
|---|---|
| $\frac{1}{3}$ $Ce_2O_3$ | 107 |
| $\frac{1}{2}$ $ZrO_2$ | 97 |
| $\frac{1}{2}$ $UO_2$ | 99 |
| $ZrC$ | 43 |
| $UC$ | ~ 34 |

**Table III** ***$\Delta G^\circ$ at 1500°K for some oxides and carbides K cal/gm atom of O or C***

| $k$ | $\Delta$ | $k^*$ | purification |
|---|---|---|---|
| 0·1 | 1 | 0·23 | 0·77 Co |
| | 2 | 0·45 | 0·55 Co |
| 0·01 | 1 | 0·027 | 0·973 Co |
| | 2 | 0·069 | 0·931 Co |
| 0·001 | 1 | 0·0027 | 0·9973 Co |
| | 2 | 0·0074 | 0·9926 Co |

**Table IV** ***variation of purification with k and*** $\Delta$

| systems | | $k$ | reference |
|---|---|---|---|
| ruthenium in uranium | | >0·1 | 3 |
| cobalt in uranium | | 0·1 | 2 |
| copper in aluminium | | 0·17 | 11 |
| zinc in aluminium | | 0·44 | 11 |
| Fe, Si, Al, Mn, in beryllium | | 0·1 | 9 |
| phosphorus | in germanium | 0·12 | 7 |
| arsenic | | 0·04 | 7 |
| antimony | | 0·003 | 7 |
| bismuth | | $4\times10^{-5}$ | 7 |
| aluminium | | 0·1 | 7 |
| gallium | | 0·1 | 7 |
| indium | | 0·001 | 7 |
| thallium | | $4\times10^{-5}$ | 7 |
| copper | | $1{\cdot}5\times10^{-5}$ | 7 |
| silver | | $10^{-4}$ | 7 |
| gold | | $3\times10^{-5}$ | 7 |
| nickel | | $5\times10^{-6}$ | 7 |
| zinc | | 0·01 | 7 |
| cobalt | | $10^{-6}$ | 7 |

**Table V** ***k values for various systems***

ganese in beryllium[9]. The explanation offered here is that purification during zone melting is very sensitive to zone speed for high values of the distribution coefficient k.† Burton et al[10] have studied theoretically the effect of speed on purification and have obtained the following equation relating the apparent distribution coefficient ($k^*$) obtained in zone melting, with the true distribution coefficient ($k$), the zone speed ($f$), the thickness ($\delta$) of the region next to the solid-liquid interface where diffusion governs the movement of solute atoms and the diffusion constant ($D$) of the solute.

$$k^* = \frac{k}{k + (1-k)\,e^{-\Delta}}$$

where $\Delta = \frac{f\delta}{D}$

Purification = quantity of solute removed = Co(1-k*)
where Co = original solute concentration

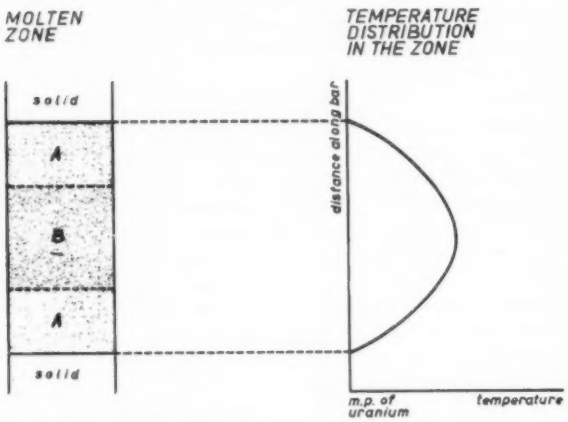


**Fig. 6** *composition of the molten zone*

In Table IV values of k* have been calculated for three values of k and two of $\Delta$. It is apparent that the purification is greatly influenced by changes in $\Delta$ and hence in $\delta$ (the degree of stirring), the diffusion constant and zone speed for k greater than 0·1.

Approximate k values for various systems are given in Table V. The solutes studied in uranium, aluminium and beryllium have $k \geqslant 0{\cdot}1$ whilst most of the solutes in germanium have $k < 1$. Theory is therefore in accord with experiment in that slow speeds are necessary zone melting uranium, aluminium and beryllium but not germanium.

The segregation of carbon is interesting because it was not due to a true zone melting process. In a true zone melting process an equilibrium is established between a massive solid and a liquid phase. The phase diagram of the uranium-carbon system (Fig. 5) indicates that upon cooling molten uranium containing carbon, solid uranium-carbide should first separate and carbon would tend to move in the opposite direction to the zones. As the concentration of carbon in these experiments is small (less than 1,000 ppm). Uranium-carbide was not present as a massive phase but as particles floating in the molten metal. If the zones had been passed downwards flotation effects would not have significantly altered the mechanism, but in these experiments the zones were passed upwards and the carbide would, therefore, tend to float away from the interface. The segregation is considered to be due to a modified flotation process. A diagrammatic representation of the postulated composition of the molten zone is shown in Fig. 6; the zone consists of three parts, the centre at a high temperature in which the carbon is dissolved (region B Fig. 6), and, at a lower temperature next to both interfaces saturated solutions containing solid uranium carbide particles as a dispersion (regions A Fig. 6). As the zone advances the uranium carbide phase, in the metal about to solidify, slowly grows giving large inclusions (Fig. 7) and as the liquid next to the interface is stagnant an ideal set of conditions is established for floating out carbon.

Oxygen was not removed more efficiently by zone melting than in a normal flotation experiment because it is only sparingly soluble in molten uranium and probably formed a separate oxide phase which floated out exactly as in a flotation experiment (Fig. 6). Unfortunately the temperature of the metal and the solubility of oxygen is not sufficiently accurately known to establish this explanation quantitatively. Carbon

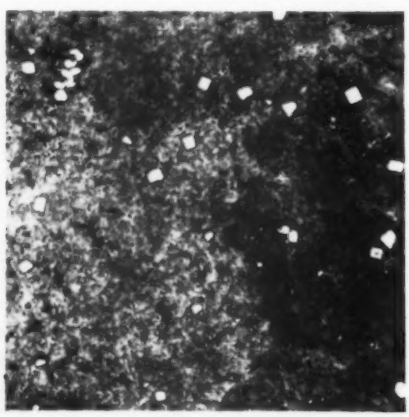

**Fig. 7** *photomicrographs show (above) at a magnification of 770, coalesced non-metallic inclusions in a uranium bar*

*When the metal has been irradiated (below—magnification 175) inclusions of uranium carbide grow at the top of the bar*

† When a solid and liquid phase are in equilibrium k is defined by : k=concentration of solute in the solid / concentration of solute in the liquid

did not behave in a similar manner because of its larger solubility; in the flotation experiment it would have been completely dissolved whilst, as already explained, during zone melting large carbide inclusions form next to the solid-liquid interface.

The above reasoning is consistent with the bad decontaminations obtained for cerium and the good ones for zirconium in irradiated material. The rare earth oxides are more stable than urania (Table III) and therefore the rare earth metals are associated with the solid urania particles in the metal, which must be molten for a sufficient time to allow the rare earths to react with these particles. During most self-slagging experiments it is necessary to keep the metal molten for 4 hours. In these experiments a particular part of the bar was molten for only 25 minutes and the bad decontaminations for cerium may therefore be due to incomplete reaction. This limitation should be overcome by using slower zone speeds. Zirconium did not behave in a similar manner, because the carbon, with which it is associated, was slowly precipitated as carbide from the dissolved state facilitating interaction between the two elements and the formation of a solid solution of zirconium carbide in uranium carbide.

Nitrogen is sparingly soluble in uranium and forms a stable nitride[12] and hence behaves in a similar manner to oxygen.

The results indicate that zone melting may be used for two purposes firstly to produce pure uranium for experimental use and secondly to decontaminate irradiated material.

To produce pure uranium it is necessary to remove metallic and non-metallic elements. A vertical furnace is required to remove non-metallics and multiple zone pass experiments with a zone speed less than $\frac{1}{4}$ in/hr would be necessary to remove metallics. Two types of apparatus appear suitable, firstly a Keck and secondly a type in which a urania crucible is used and the uranium is kept in the plastic $\gamma$ phase.

The decontamination of irradiated uranium requires the removal of non-metallic elements with their associated fission products in a vertical furnace. A zone speed of 3 in/hr may be used. A crucible could be used as a certain amount of contamination may be tolerated although if it is required to reduce the amount of active waste to a minimum a Keck type apparatus might be more suitable.

The more specific conclusions reached are that:

1. Soluble metallic elements have to be removed with slow zone speeds and density difference may be harnessed in a vertical furnace to increase the separation of metallics and non-metallics.
2. Zone melting may be used as an improved self-slagging process to increase the decontamination of carbon and fission products from uranium. Certain minimum concentrations of the non-metallics, carbon and oxygen, are necessary to decontaminate uranium efficiently from its fission products.

The individual fission product analyses carried out by Mr. G. J. Hunter and the experimental assistance of Mr. E. Barnes and Mr. M. Gardner is gratefully acknowledged. The author is also indebted to the Director of the Admiralty Materials Laboratory for the loan of a Keck type apparatus.

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*An introduction to*

# Control of nuclear reactors

by R. J. Cox AERE, Harwell

continued from page 114, July 1956

## 6 Reactor transfer function

A useful method of describing the dynamic behaviour of an element in a servo system is that of the transfer function. This can be applied to nuclear reactors. The reactivity of the reactor is varied by a small amount in a sinusoidal manner and the resultant variation in power level is measured. Fig. 3 shows the characteristics for CP-2, a typical graphite moderated reactor, when the mean reactivity is zero.

In the absence of delayed neutrons, the reactor would act as an integrator, displaying a 90° phase lag over the range of interest and a fall in amplitude of 6 dB per octave. At zero frequency the gain of the reactor would be infinite. It will be noticed from Fig. 3 that for this particular reactor the phase lag is only 20° at around 0·25 c/sec but is asymptotic to 90° at zero and infinite frequency. This phase advance of 70° is a function of the delayed neutrons present and will therefore depend upon the reactivity of the reactor. When the reactivity is positive, the delayed neutron effect is less and the phase

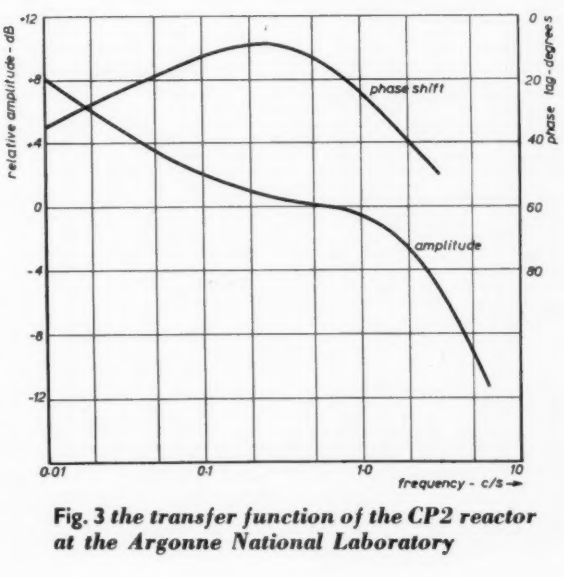



**Fig. 3** ***the transfer function of the CP2 reactor at the Argonne National Laboratory***

*THE MULTIPLICATION FACTOR and reactivity of a reactor are explained and defined and methods described for controlling them, taking into account the effects of delayed and photo neutrons. The solution of the reactor kinetic equation is discussed and the importance of the reactor transfer function emphasised. Changes in reactivity during operation due to depletion of fuel and poisoning are mentioned and the article concludes with the development of the principles of automatic control. This article, and a future one, are based on post-graduate lectures recently given at Cambridge University.*

*L'AUTEUR EXPLIQUE et définit le facteur multiplicateur et la réactivité d'un réacteur, et expose les moyens de les contrôler, en tenant compte des effets des neutrons retardés et des photoneutrons. Il étudie la solution de l'équation cinétique de réacteur et insiste sur l'importance de la fonction transfert du réacteur. L'auteur mentionne les changements de la radioactivité en cours de fonctionnement, dus à l'épuisement du carburant et les intoxications, et il conclut en développant les principes du contrôle automatique. Cet article, ainsi qu'un article qui lui fera suite, est basé sur des conférences destinées aux diplômés, données récemment à l'Université de Cambridge.*

*MULTIPLIKATIONSFAKTOR UND RADIOAKTIVITÄT eines Reaktors werden erklärt und definiert und Verfahren für deren Steuerung unter Berücksichtigung der Wirkung von verzögerten und Photo-Neutronen beschrieben. Der Verfasser bespricht die kinetische Reaktorgleichung und betont die Wichtigkeit der Übertragungsfunktion des Reaktors. Die Arbeit befasst sich weiterhin mit den während des Betriebs auftretenden Veränderungen der Radioaktivität, die durch Brennstofferschöpfung und—vergiftung verursacht werden, und abschliessend wird die Entwicklung der Grundlagen der selbsttätigen Steuerung besprochen. Dieser Artikel—und ein weiterer, der später folgen soll—gründen sich auf Vorträge, die kürzlich in Cambridge für Hörer mit abgeschlossener Hochschulausbildung gehalten wurden.*

*SE EXPLICAN Y DEFINEN el factor de multiplicación y la reactividad de un reactor, y también se describen los métodos para controlarlos, teniendo en cuenta los efectos de los neutrones retardados y fotoneutrones. Es discutida la solución de la ecuación cinética del reactor y subrayada la importancia de su función de transferencia. Cambios en la reactividad durante el funcionamiento, originados por el agotamiento del combustible y contaminación, son comentados, y el artículo termina con el desarrollo de los principios del control automático. Este artículo, y otro que se publicará en el futuro, están basados en las conferencias de un curso de ampliación de estudios celebrado recientemente en la Universidad de Cambridge.*

*ОБЪЯСНЯЕТСЯ И ОПРЕДЕЛЯЕТСЯ мультипликационной и реактивный фактор реактора, а также описываются методы его регулирования с принятием во внимание действия затяжсых нейтронов и фотонейтронов. Обсуждается решение кинетического уравнения реактора и подчеркивается важность его передаточных функций. Статья касается и изменений реактивности во время действия в результате истощения горючего и отравления. В заключение говорится о развитии принципов автоматического регулирования. Эта статья так же как и другая которая еще появится основана на недавно прочитанных в Кембриджском университете лекциях для окончивших уже университетский курс.*

## Erratum

A mistake occurred in equation 8 of the first instalment of this article. It should read:

$$n=\left(n_0+\frac{S\tau}{(K_{eff}-1)}\right)e^{\frac{(K_{eff}-1)t}{\tau}}-\frac{S\tau}{(K_{eff}-1)}$$

advance will be less. Correspondingly, a sub-critical reactor will have a larger phase-advance.

In all nuclear reactors the reactivity is a function of the temperature. For most reactors the temperature coefficient of reactivity is negative. In other words, as the power level and therefore the temperature of the reactor increases the reactivity will decrease. This has important effects on the reactor transfer function. Firstly the phase shift will be asymptotic to 0° at zero frequency and it can cause an additional phase advance effect in a frequency region dependent upon the time of response of the temperature coefficient effect. Also the gain of the reactor will have a finite value at zero frequency. This means that the reactor ceases to act as an integrator. The control rods cease to determine the rate of change of power. The control rod position will now be dependent upon reactor power (for zero reactivity), although the position will still wander because of other long-term reactivity changes. The magnitude of this effect depends upon the magnitude of the temperature coefficient of reactivity and upon the temperature of operation of the reactor. Power reactors normally run at high temperatures, so this effect is normally large and represents a powerful stabilising influence. However, it means that the power level of the reactor is a function of its temperature (for constant control rod position). Hence reducing coolant flow would increase its temperature which would cause its power output to decrease, thus reducing the temperature rise. For this reason, there is a close coupling in a nuclear power plant between the reactor and the steam side of the plant. Variations in load on the electrical generators are reflected through the steam and coolant temperatures right back to the reactor.

## 7 Changes in reactivity during operation

### 7.1 Depletion of fuel

The fuel of a reactor will be consumed as its operation continues. The time for which one fuel element can be used depends considerably upon the reactor type and the fuel element design. The limiting factor may be the loss of reactivity either due to depletion of fissionable material or the build-up of neutron absorbing fission products. Or the limit can be due to the change in structure of the fuel elements due to the accumulation of chemically foreign fission products.

### 7.2 Xenon poisoning

The most significant fission product from the control aspect is xenon, which has a very high capture cross-section for neutrons. It is not a direct fission product, but arises from the decay of $Te^{135}$

$$_{52}Te^{135}\xrightarrow{\beta\,(2min)}{}_{53}I^{135}\xrightarrow{\beta\,(6{\cdot}7h)}{}_{54}Xe^{135}$$

and itself undergoes decay:

$$_{54}Xe^{135}\xrightarrow{\beta\,(9.2h)}{}_{55}Cs^{135}$$

After a reactor has been running at constant power for some time, the total amount of $Xe^{135}$ in the reactor will have reached equilibrium. The $Xe^{135}$ will be produced by the decay of $Te^{135}$ and $I^{135}$ at the same rate as it is being destroyed by neutrons and by its

own decay. When a reactor is shut-down the $Xe^{135}$ will continue to be produced by the decay of the $Te^{135}$ previously produced in the reactor, but its destruction by neutrons will cease. The level of poison will build-up to a peak and then decay again. This process can complicate the reduction in power level of a high flux thermal reactor. Fig 4 shows a curve of reactivity against time after a reactor has been shut-down after running for some time with an

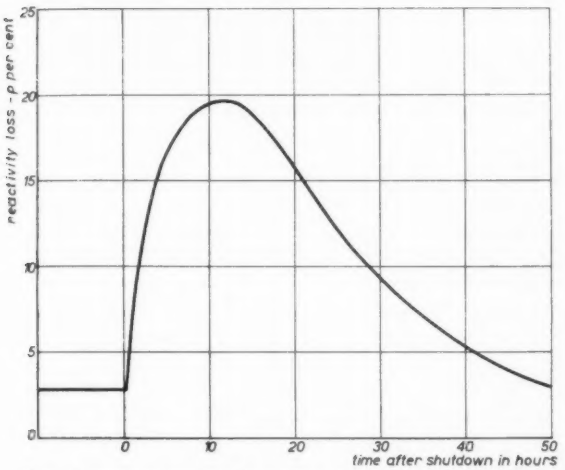



Fig. 4 *xenon poisoning transient following shut-down of a natural uranium heavy-water reactor (average flux approximately* $5 \times 10^{13} n/cm^2/sec$)

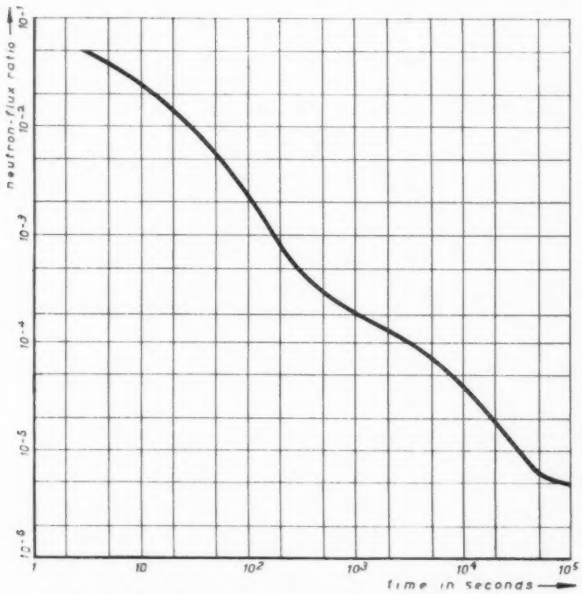



Fig. 5 *the flux decay in a heavy-water reactor*

average neutron flux of about $5 \times 10^{13}$ n/cm²/sec. It will be noticed that the reactivity loss due to Xe has increased to about 18 per cent after about 11 hours. This could well be more than the entire excess reactivity of the reactor. The reactor could not be restarted until the poison had decayed, which, it will be noticed, could mean a wait of up to two days.

The initial rate of change of reactivity for a step function change in power is quite large. It is in a direction to be a de-stabilising influence. With flux levels above about $10^{15}$ n/cm²/sec it becomes one of the main factors determining the design of the control system.

It should be noted that the cross-section of $Xe^{135}$ to fast neutrons is much less than for thermal neutrons. For this reason, the effect of xenon poisoning is very much less severe in fast reactors.

## 8 Instrumentation

In order to be able to control a reactor it is necessary to be able to measure the power developed. When running at constant power we have seen that 6 per cent of the heat is produced, not immediately, but by beta and gamma decay processes which change with power level relatively slowly. For this reason temperature measuring equipment is limited to a relatively narrow useful region around the normal operating level. Also, because of the exponential change of power with time when operating at low powers, it becomes essential to monitor the power level by measuring the neutron population of the reactor. This cannot be done directly. But as an almost constant fraction of the neutrons generated escape from the reactor, we can measure the population by measuring the flux of escaping neutrons at one or more points surrounding the reactor.

### 8.1 Range of neutron fluxes

The range of neutron fluxes that is required to be measured depends upon the reactor type. Fig. 5 shows the decay of neutron flux at a point near a heavy-water reactor after it has been shut-down. It will be seen that after a day ($8{\cdot}6 \times 10^4$ seconds) the flux has decreased to $5 \times 10^{-6}$ of the operating flux level. It takes several days to fall by a further factor of 5. Thus, neutron flux measuring equipment covering a range of $10^6$ would suffice for normal operation.

However, in reactors that do not have a photo-neutron background, the range of neutron flux could well be 10 or even 14 decades. This range of fluxes would make the instrument design very difficult. With graphite-moderated reactors the range can be reduced to 7 or 8 decades by inserting in the reactor antimony-beryllium or sodium-beryllium sources. These are regenerated while the reactor is running and are therefore self-sustaining. In other reactors radium-beryllium sources are used. These sources are not usually regenerated while the reactor is running but the long half-life of radium provides an almost constant source strength.

## 9 Automatic control

### 9.1 Simple power level control

A simple method of automatically controlling the power level of a reactor is shown in Fig. 6. The ion-chamber current flowing through the resistor R produces a voltage proportional to the power level. This voltage is in series with a constant "backing-off" voltage, the difference of potential being applied to the control rod servo system. Because the control rods

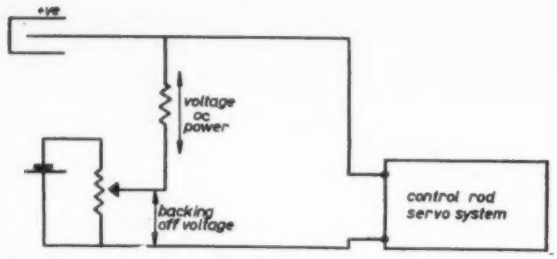



**Fig. 6** *a simple method of automatic power level control*

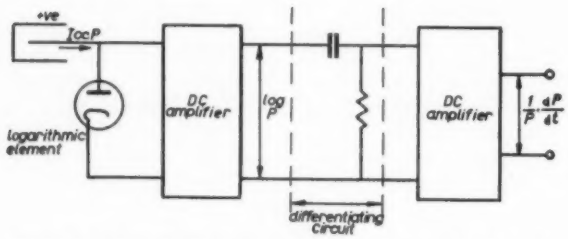



**Fig. 7** *the block diagram of a reactor period meter*

act as accelerators to the reactor power, it is necessary to use a type of control-rod servo system in which the rod velocity is proportional to the applied signal.

To those familiar with automatic control systems, it will be apparent that as the system has no "anticipation" term, when going from one power level to another, the power level must "overshoot" the demanded level. This need not be serious if the change in levels is relatively small and if the system is not too "tight".

The system will oscillate continuously if the gain around the complete loop of reactor, ion-chamber instrument, servo system back to the reactor, is greater than unity when the phase shift has reached 360°. In general, accuracy is improved as the (low frequency) loop gain is increased, that is, as the system is made "tighter". By referring to the transfer function diagram (Fig. 3), it is apparent that the limiting loop gain for stability can be higher if the upper frequency limit of the power level instrument plus servo system is about 0·5 c/sec.

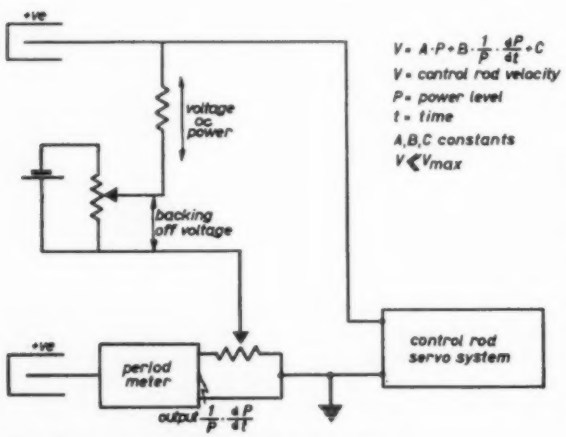



**Fig. 8** *an automatic start-up system*

### 9.2 With Differential Signal—Automatic Start-Up

The tightness of the system could be improved and the overshoots eliminated by adding a term proportional to rate of change of power. This can be derived from the period meter—shown in block form in Fig. 7. The output of the first amplifier of this instrument is proportional to the logarithm of power. The following unit differentiates this signal and so gives an output proportional to $\frac{d}{dt}$ (log $n$) i.e. proportional to $\frac{1}{P}\frac{dP}{dt}$. This output is inversely proportional to the reactor period and the meter on the output is usually calibrated in either reactor period or reactor doubling time.

Fig. 8 shows the block diagram of a system using the differential term. The velocity of the control rod is now given by

$$V = A.P. + B\frac{1}{P}\frac{dP}{dt} + C \qquad (14)$$

The damping term $B\frac{1}{P}\frac{dP}{dt}$ has a 90° phase lead and therefore allows much larger values of loop gain to be used and still have the system unconditionally stable.

By using moderate values of the parameter $B$ the system can be arranged to be critically damped. There are advantages, however, in using much larger values. Suppose the power level of the reactor is very low compared to the demanded level, then zero rod speed can correspond to $B\frac{1}{P}\frac{dP}{dt} + C = 0$. That is, the system would attempt to maintain the reactor period at some constant level, depending upon the value of $B$ and $C$. For particular values of these parameters, the system can be considered to have a demanded level of period. When changing from one power level to another, the control system will ensure that the reactor period never falls below this demanded level. Thus, from the safety point of view, there are considerable advantages in using large values of $B$.

There is also a further advantage in large values of $B$. The system can be used for controlling the start-up of a nuclear reactor and is in fact, the system that has been used for automatic start-up of BEPO for over 3 years. With this system, starting-up can be considered as changing from zero power to the demanded level. However, it must be remembered that a diverging reactor has a lower contribution of delayed neutrons than a critical reactor and this can cause the reactor to oscillate in period about its demanded level. Also if the reactor power level signal has a significant level of noise, this noise will be accentuated by the differential signal and can be the factor that determines how closely the power can be kept to the demanded level.

Much of the material of this article has already appeared in a number of papers read before the *Institution of Electrical Engineers* and the *Institute of Radio Engineers*.

A companion article—*the safety of reactor control systems*—by J. Walker will appear in next month's NUCLEAR POWER.

*Originally designated E443, but now known as DIDO (derived from $D_2O$ or D,D,O) Harwell's new heavy-water moderated and cooled research reactor is contained in a pressure-tight steel building here seen in course of erection*

# DIDO reactor . . .

THE LATEST BRITISH REACTOR to be completed is the new heavy-water research reactor DIDO at the Atomic Energy Research Establishment, Harwell, criticality of which is expected to be achieved this month. Modelled closely on the CP5 reactor, at the Argonne National Laboratory of the US Atomic Energy Commission, which was first put into operation in February 1954, DIDO is however a rather more powerful instrument with a maximum thermal neutron flux of $10^{14}$ neutrons/cm$^2$/sec compared with CP5's maximum of $6{\cdot}2 \times 10^{13}$ (Argonne director Walter H. Zinn stated at Geneva, however, that this figure could be stepped up to about $8 \times 10^{13}$).

The purpose of DIDO is twofold: to provide a powerful tool for reactor research and development and a source of isotopes of high specific activity. The later requirement will be met with an annual production equivalent to 30,000 curies of cobalt 60.

Three general types of experimental facility are provided: neutron beams, irradiations without close control, and irradiations with close control of environment. To achieve this a total of no less than 59 experimental holes are provided of varying size and shape. It is of course not anticipated that all these holes will be used simultaneously since, apart from the question of available space round the reactor, there is loss of reactivity to be taken account of. The reactor is designed for a heat load of up to 10 MW from the core and 1 MW from the experimental facilities. The total cost is said to have been about £2m.

### Box-type fuel elements

The fuel used in DIDO is almost pure $U^{235}$, a total of up to 2·5 kg being required. This is in the form of uranium-aluminium alloy plates, clad with pure aluminium to form a sandwich. The plates are slightly curved to permit distortion under heat and radiation conditions and eleven of these, welded into a box-like structure about 60 cm long form an individual fuel element. These in turn are fitted into tubes which pass through the tank top plug. The maximum number of elements is 25 arranged in a lattice to fill an equivalent cylinder about 80 cm diameter. At their lower end, the elements are held in fittings on a horizontal tube plate on the base of the tank.

The reactor vessel or calandria containing the fuel elements and the heavy water is a cylindrical tank in 99·5 per cent pure aluminium manufactured by the A.P.V. Co. This is 200 cm in diameter. Its bottom is dished and it is supplied with pipe branches and thimble tubes as required for the experimental facilities. This is the centre of the whole reactor. Surrounding the sides and bottom of the tank is the graphite reflector which consists of machined blocks to a total thickness all round of at least 60 cm. The weight of the calandria and its contents is taken down through the graphite to the supporting structure by four welded legs.

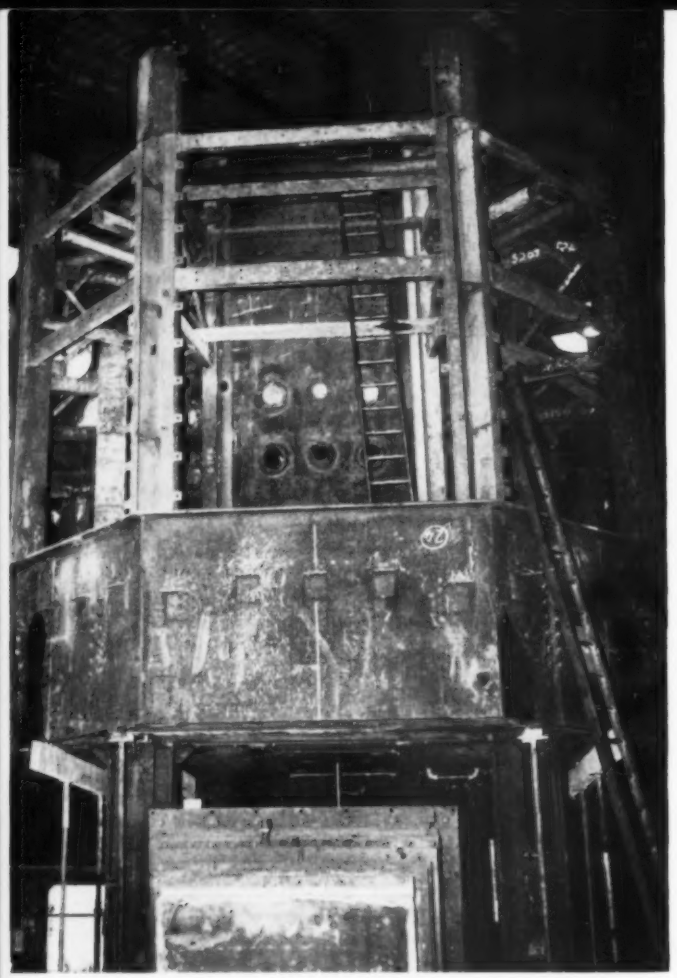
### Water cooled thermal shield

The graphite is held in place inside a double-walled steel tank with an internal diameter of about 10 ft 10 in. and about 9 ft high. Between the graphite and steel is a thin layer of boral sheet, bonded to the steel with lead. The boral (boron-aluminium) consists principally of boron carbide and is intended to absorb thermal neutrons without the emission of capture gammas and so reduce the amount of biological shielding necessary. The void formed by the double skin of the steel tank is filled with lead in which are embedded copper cooling coils which run vertically up and down the active area of the calandria. These carry distilled light water. The base of the tank is given a similar treatment. This forms the thermal shield.

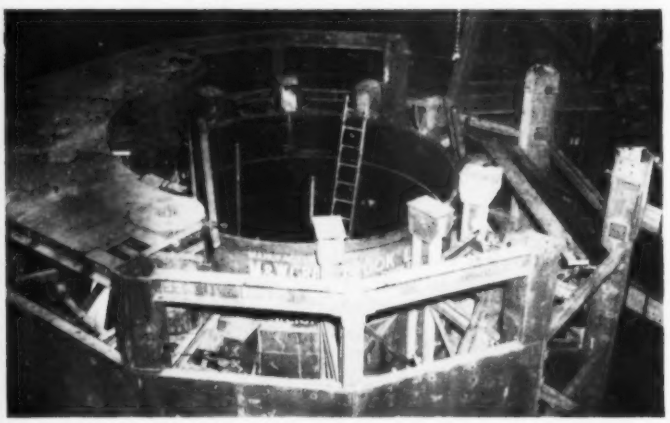
The biological shield is in the form of an irregular decagon, about 22 ft across the flats and about 19 ft high from the base to the platform on top. This is faced on the outside and bottom with steel plate and filled with dense aggregate concrete giving a minimum thickness of about 5 ft. Strength for this structure is given by a system of radially placed vertical steel joists and channels round the steel tank and by channels welded in pairs to the external cladding to form the corners. The shield is pierced by many experimental holes and by a large graphite thermal column.

The whole structure is carried on a massive grid of steel joists embedded in the concrete and supported by four legs formed from welded steel sections going down to the ground floor level where is situated the plant room for the heavy water pumping and heat exchanging facilities.

Turning now to the top of the reactor, the calandria is sealed by a hollow steel plug about 2 ft 9 in. thick



*The supporting structure (above) is of welded steel construction and the whole weight is taken down to the foundation through four massive steel legs. Below the reactor in a square plate can be seen the heavy-water inlet and outlet connections. The biological shield is clad externally with steel plate (below) and filled with concrete. The top shield—not yet fitted in this view—is of 10 in. steel plate*



filled with concrete and fitting closely into the calandria tank. Gas seals are fitted, for the atmosphere of the tank is helium. The lower part of this shield consists of a pair of steel plates, the space between being filled with lead. There is also a layer of cadmium. The upper part is a steel plate and this is pierced by numerous holes which are connected via steel tubes to the lower thermal shield thus providing facilities for fuel rods and the vertical experimental holes. Above the whole tank, but clear of it, and forming the top platform of the whole reactor is a 10 in. thick steel plate—also pierced by appropriate holes for fuel rod charging. These are fitted with flush-fitting steel plugs. The central portion of this plate is removable in order to permit access to the tank if necessary and the thickness is stepped into the fixed part of the shield. The remainder of the upper platform away from the immediate vicinity of the steel tank is of welded steelwork clad with steel plate.

The cooling is of course by the heavy water. This enters the base of the calandria through three 9 in.

## . . . DIDO

pipes closely grouped at the centre. Inside the tank a tube plate is welded across the base and it is fitted with cup fittings to receive the fuel rods and the vertical control rods. From the plenum chamber so formed the heavy water rises through the fuel element boxes and then out through radial openings into the tank. Four 7 in. bell-mouth weir pipes are fitted in the base of the tank and the hot heavy water flows down these to a header in the plant room and so through a battery of three heavy-water pumps to three heat exchangers. The pumps are of the submersible glandless type manufactured by Hayward Tyler & Co Ltd. Each unit comprises a single-stage centrifugal pump, direct-coupled to a 60 hp, 1460 rev/min, 415v, 3-phase motor. Both pump and motor are enclosed in a stainless-steel shell the top of which forms the suction inlet. The materials of construction are stainless steel and aluminium, and both thrust and journal bearings are of the tilting pad type employing stainless-steel pads with plastic thrust-disc and journal sleeves. In order to exclude all organic contamination, the pumps were assembled under conditions of scrupulous cleanliness. Purity of the heavy water is maintained by an ion-exchange system.

### "Railway signal" control arms

The three heat exchangers are cooled by ordinary water which, on leaving the DIDO reactor building flows across in 10 in. mains to a battery of eight vertical cooling towers. The heavy water reservoir is a large cylindrical tank and a safety dump tank is fitted so that if necessary the level in the calandria can be rapidly lowered to the outlets. This removes reactivity by removing the top reflector but the level cannot drop low enough to uncover the fuel elements.

All pipes leaving the reactor vessel are fitted with expansion joints.

The control system is in many respects similar to the ANL CP5 but there are detailed differences. The primary shut-off and control function is performed by six cadmium arms of the "railway signal" type. The fuel elements are arranged in rows of 4,6,5,6,4, and the signal arms move in a vertical plane between the rows and on the outside. The normal position for fully "out" is 0° (*i.e.* horizontal) and for maximum absorption the angle to the horizontal is about 56°. They may, however, be dropped to 90° and, in this position, the whole actuating mechanism and signal arm may be withdrawn through the top plug and the top shield.

Unlike the CP5's signal arms, DIDO's are not worked by horizontal rods passing out of the tank through a gland. They are in fact operated from outside the top plug by means of a mechanical linkage, sealed at the bottom by a bellows expansion joint and actuated outside the plug by a 90:1 worm

## reactor

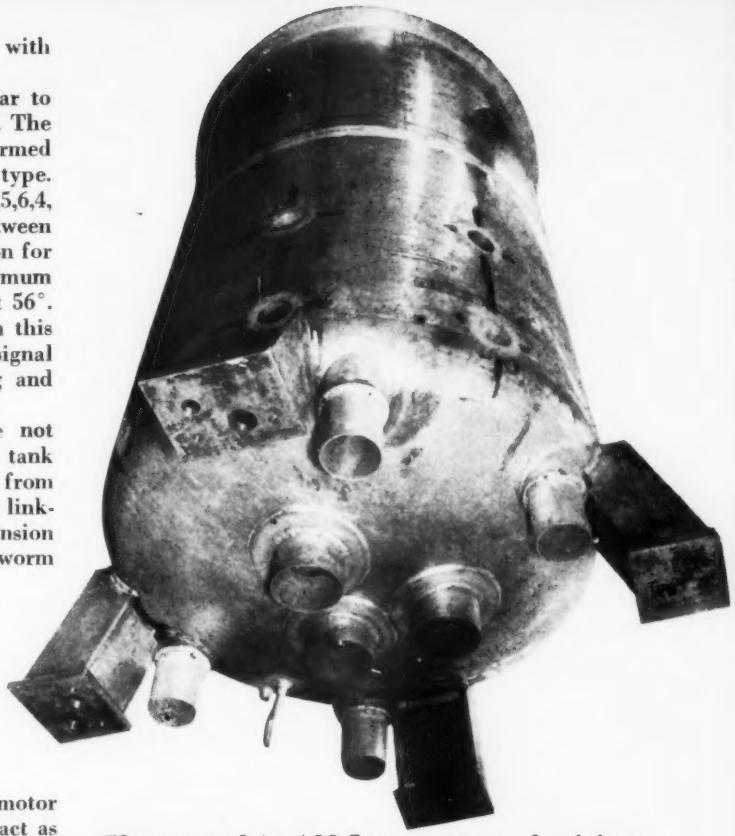
reduction gear driven in turn by an electric motor below the top steel shield. These six motors act as slaves from a single master unit which forms part of the reactor's control instrumentation. There is also a unit which monitors and adjusts any misalignment between the motors so that the control rods move absolutely together.

In addition to the swinging control rods, there are two normal vertical safety rods operating in aluminium cylinders and located on fuel-element lattice centres on the outer rows. Finally, there is a single fine control rod. This also is in an aluminium thimble and consists of a cadmium absorber sandwiched between two stainless steel tubes. Cooling water flows down the centre and then up the sides of the rod. The rod is moved by an irreversible screw thread jack turned by a 4:1 worm reduction gear from a servo motor. Its total travel is 24 in.

The atmosphere above the heavy water in the core tank is of helium and the space between this vessel and the outer steel tank—a space filled mostly with graphite blocks—is also charged with helium.

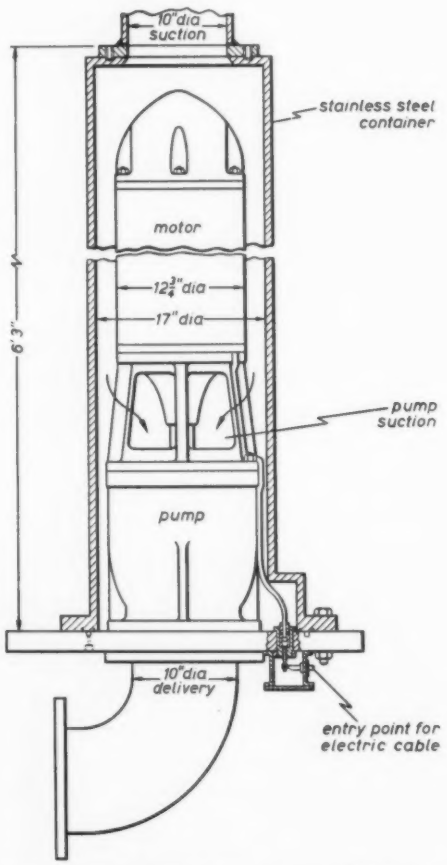
In order to contain any radioactivity should the unlikely event of a catastrophic accident occur, DIDO is contained in a special building. Unlike the ANL's CP5, however, which is in a prestressed concrete shell, the DIDO building is a cylindrical steel shell. This is 70 ft diameter and the same height to the top of its slightly domed roof. It is constructed in preformed steel plates reinforced externally by vertical channel sections which also cross the domed roof radially to meet at the apex. The structure is welded throughout and was pressure tested.

Since the pressure in the building is maintained at a value slightly below atmospheric, the floor is also



***The core tank is of 99.5 per cent pure aluminium and is supported on four legs. Three heavy water inlets are grouped at the centre of the base (above) while the four outlets are towards the periphery. Penetrating the walls, experimental facilities are in the form of thimble tubes. The fuel elements are fitted to a tube plate over the inlet plenum chamber (below). In this view the four heavy water overflow weir pipes can be seen. The pipe going right through the tank is a 4 in. by 2 in. oval experimental facility passing the region of maximum flux***

*In order to avoid any possible contamination from dirt or dust, engineers clad in sterile clothing assemble one of the three heavy-water pumps under scrupulously clean conditions*




***Basically similar to a submersible bore-hole pump, the 60 h.p. heavy-water pump is enclosed in a 17 in. stainless steel shell, the electrical connection being taken through a gland***

of steel, and a diaphragm, lowered in the centre to provide a semi-basement, rests on the mass-concrete foundations and is welded to the walls, thus forming a completely closed shell.

Access to the reactor is gained through three air locks. On the ground level there is a large one through which trucks may be driven to convey heavy equipment to and from the adjacent building. On the same level communicating with the open air, is a smaller air lock which serves as an emergency exit for personnel. The normal entrance for staff is through another air-lock at the level of the reactor upper platform and this, like the vehicle lock, connects with the adjacent building.

The ground floor in the pressure shell contains most of the ancillary plant such as the heavy water storage, pumping and heat exchanging systems, the thermal shield cooling system, the experimental hole cooling system, gasholders for the helium used in the tank and reflector, and a storage for fuel elements.

A short stairway leads to the reactor floor where the control room is situated. Above, is a 20-ton gantry crane running on a circular track round the building.

### Hot laboratory facilities

Although as much space as possible was left for experimental work round the reactor this is necessarily rather limited owing to the general cost of the special building. Consequently as much work as possible will be done in the adjacent building. This is fully equipped to deal with "hot" materials and there is direct access to the reactor building both via the vehicle air-lock and the upper personnel lock. This building is 100 ft long and 30 ft wide. A deep pond is provided in the floor so that highly-active materials can be examined under water. Another 20-ton gantry crane provides mechanical handling facilities. An office block, electrical plant room, effluent delay tanks and the cooling tower battery completes the site arrangements.

Of the experimental holes, there are a total of eight which enter the aluminium calandria horizontally in the form of thimble tubes. There is also an oval tube which passes horizontally right through the tank. From the top plug, a total of eighteen tubes enter the heavy water while a further ten enter the graphite reflector. These holes vary in size from 2 in. to 10 in. Below the aluminium core vessel two rectangular experimental holes run horizontally right through the graphite. In addition to these facilities there is a 5 ft square thermal column with nine 4 in. holes.

The experimental holes are fitted with steel concrete-filled plugs. The tips of these are water-cooled and a gas connection is fitted so that the holes can be purged with carbon dioxide and sealed in order to reduce argon-41 activity.

*The main contractor for DIDO was Head Wrightson Processes Ltd*

*The photographs are by courtesy of the United Kingdom Atomic Energy Authority, the A.P.V. Co Ltd, and Hayward Tyler and Co Ltd*

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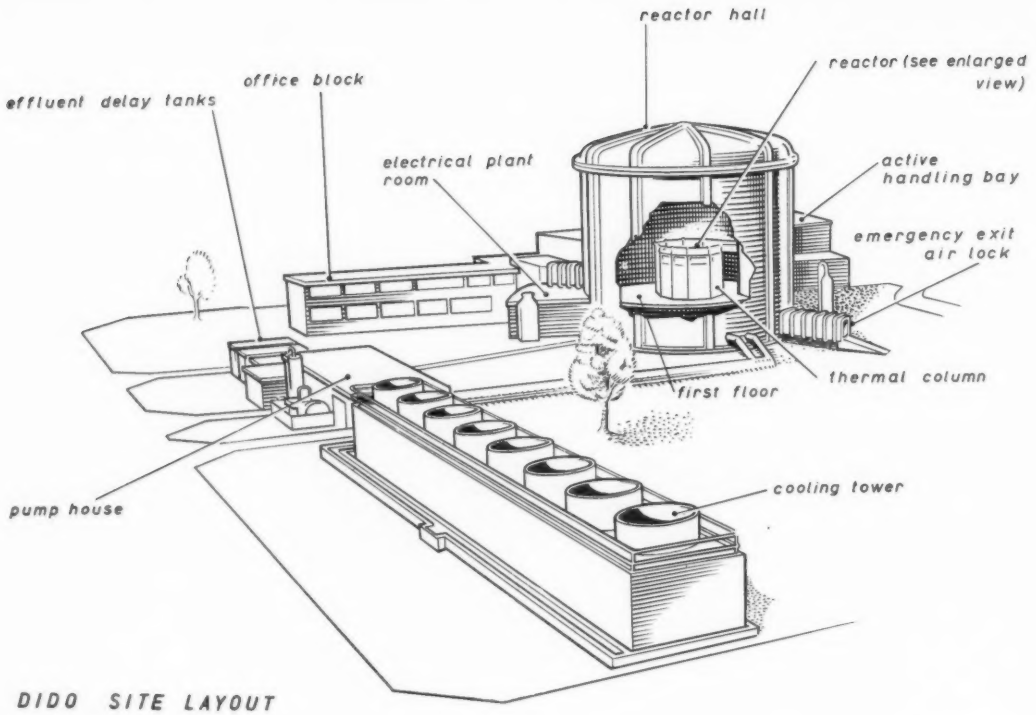


DIDO SITE LAYOUT

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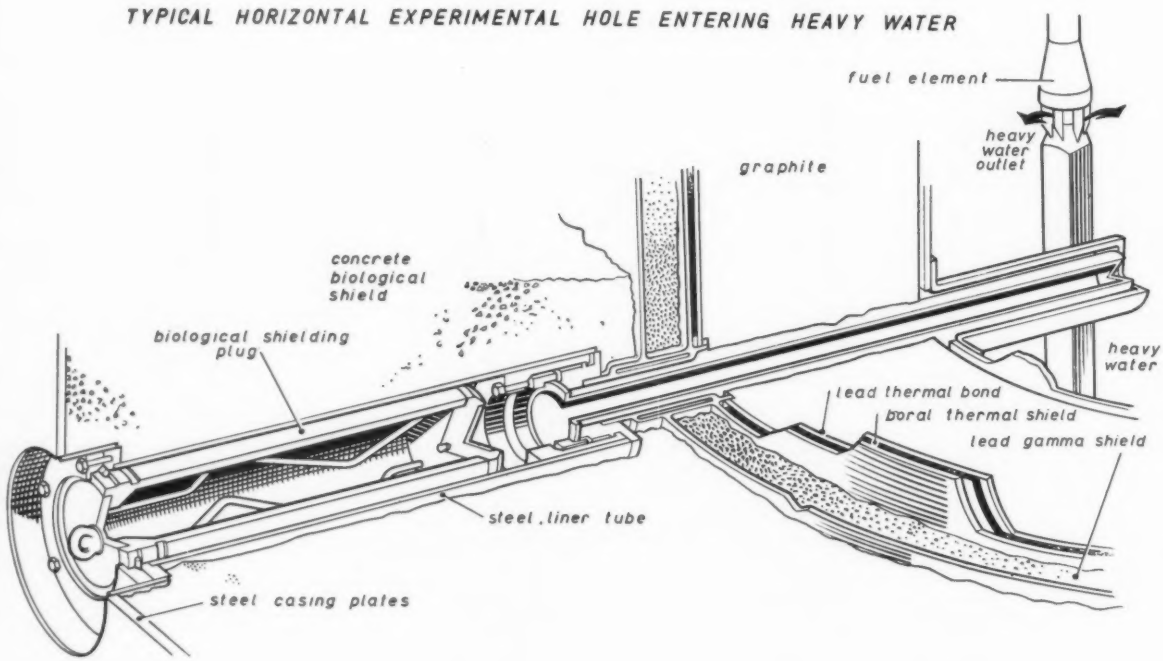
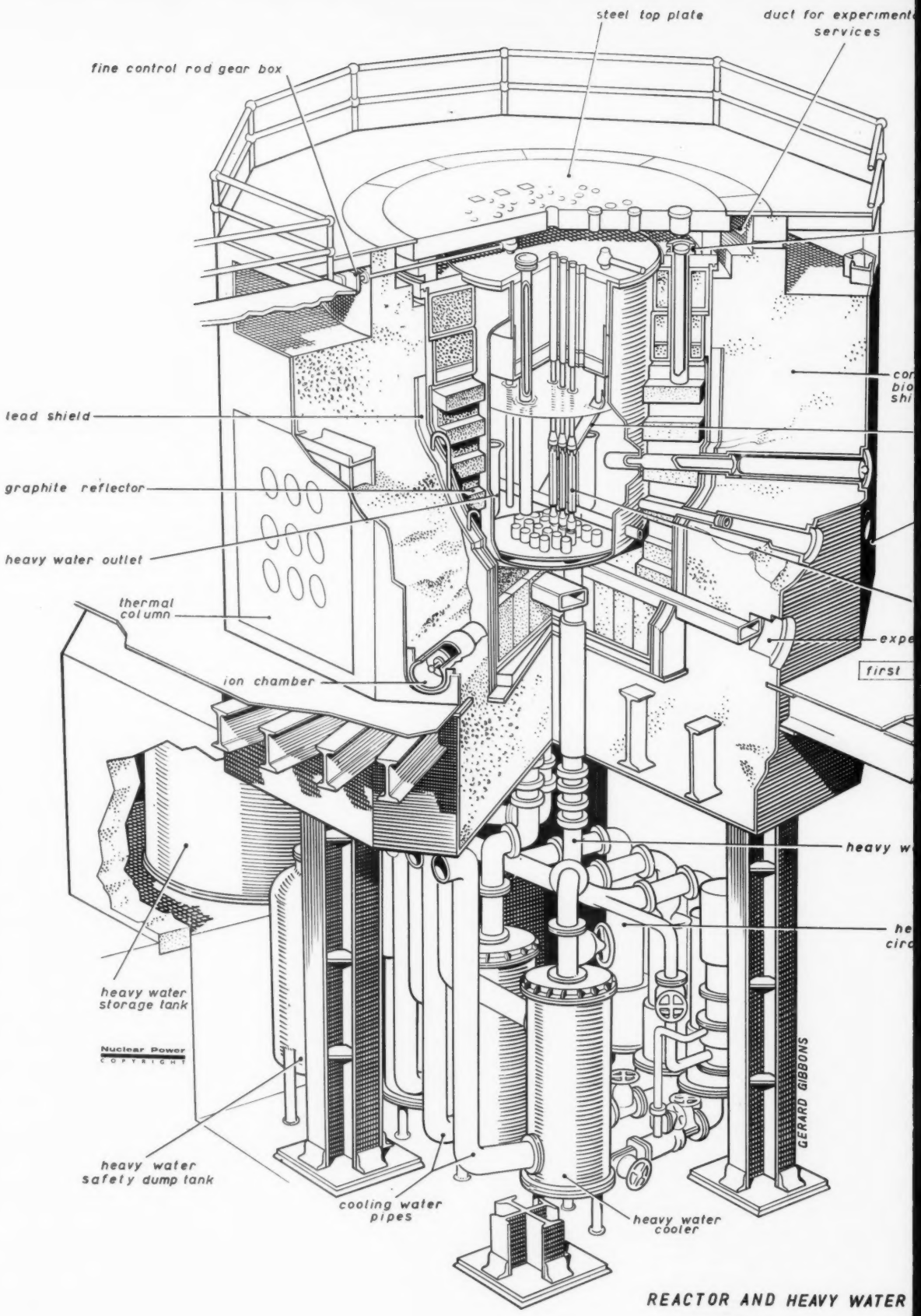
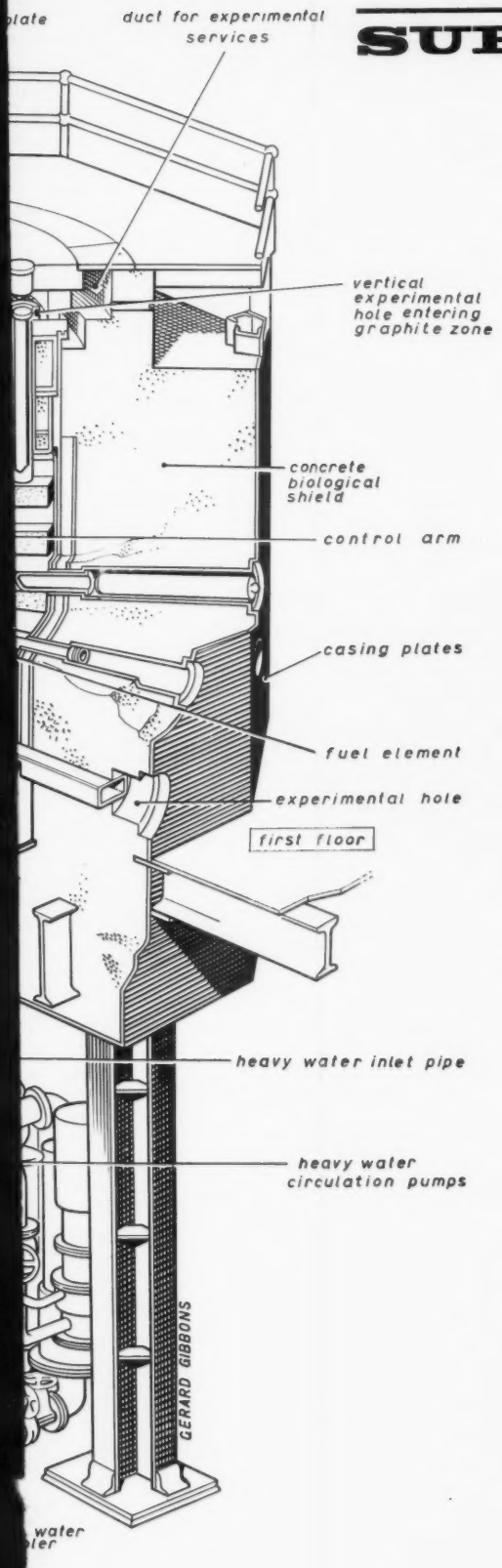
TYPICAL HORIZONTAL EXPERIMENTAL HOLE ENTERING HEAVY WATER






REACTOR AND HEAVY WATER

SUPPLEMENT 2




ACTOR AND HEAVY WATER PLANT ROOM

# DIDO heavy-water research reactor

*Before installation of the aluminium core tank, workmen place some of the thousands of machined graphite blocks which form the reflector. Heavy-water inlet pipes will enter the tank through the three large central holes*

AUGUST 1956

Nuclear Power
the journal of British nuclear engineering

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*REPORTS of work by Soviet scientists to harness the energy produced by the fusion of light elements has aroused world-wide interest. Dr P. C. Thonemann, Deputy Chief Scientist, General Physics Division, The Atomic Energy Research Establishment, Harwell, interprets*

# The Russian controlled thermonuclear experiments

## 1. Introduction

The recent lecture at Harwell by Academician Kurchatov on the possibilities of a thermonuclear reaction in a gas discharge[1] has excited great interest. This is the first time a major power has released scientific information on controlled thermonuclear reaction research and the results are of great scientific importance, particularly the announcement of the production of high energy x-rays by an ionised gas.

It has been known for over twenty years that when light nuclei, moving at high velocity, collide with each other, they sometimes combine and in doing so produce different nuclei and considerable surplus energy. The two most probable reactions are those between tritium and deuterium and between deuterium and deuterium (abbreviated T-D and D-D) both of which are hydrogen isotopes.

According to Einstein's relation the energy released is $\triangle E = \triangle MC^2$ where $\triangle M$ is the reduction in mass and $C$ the velocity of light. The possibility exists, therefore, of using these reactions as a source of power and this possibility is extremely attractive because of the abundance of suitable elements as "fuel." The latent energy in the oceans of the world due to their deuterium content is many times greater than that of a similar volume of petrol. The word "thermonuclear" is applied to those reactions between nuclei which takes place in a gas at high temperature and in which the nuclei collide with random velocities. It is not immediately obvious that the production of a controlled thermonuclear reaction is the best way of achieving an efficient fusion process but the Russian experiments are clearly a first step in this direction. They do not claim to have produced a thermonuclear reaction in deuterium, far less an efficient one. Nevertheless the results obtained are of great interest because of the unexpected phenomena encountered. In order to assess the importance of this work it is first necessary to examine the condition under which a thermonuclear reactor might operate.

## 2. Why thermonuclear reactions?

The simplest method of producing nuclear reactions is to bombard a solid target with high energy nuclei which have been accelerated electrically through potential differences of 10 kilovolts or more. Even at best, however, less than one in a hundred thousand of the bombarding particles leads to a reaction. The T-D reaction has the highest known cross-section for collision between charged particles but the power output in the form of high energy reaction products is less than 1% of the power required to accelerate the incident nuclei. Nearly every nucleus incident on the target is brought to rest by the target atoms without having penetrated close enough to a target nuclei to bring about a nuclear reaction. To eliminate this unwanted energy loss all the target atoms must be raised to an energy sufficiently high so that collisions between the incident particles and the electrons and nuclei in the target, do not on the average lead to a slowing down of the bombarding particles. Collisions between the bare nuclei are elastic* so that after repeated collisions a nuclear reaction will finally occur, thus nuclei will make many elastic collisions before reacting, and they will attain a random velocity distribution, closely Maxwellian, before an appreciable fraction have taken part in a reaction. It might be thought possible to dispense with the electrons altogether since they are a nuisance and only increase the energy loss. However, the resulting gas of positively charged nuclei, which it is possible to confine, is so tenuous that the reaction rate is negligible. One is led to the view that an economic light element reactor cannot consist of beams of high energy nuclei colliding with other beams or with stationary atoms in targets but will consist of a hot mass of uncharged gas with electrons and nuclei moving in all directions and with random velocities. Such a system can justifiably be called a thermonuclear reacting system.

Such a gas will radiate electromagnetic energy.

* Nuclei suitable for possible fusion reactor have no excited states and radiation due to nuclear collisions is negligible

*IN A RECENT LECTURE at Harwell Academician Kurchatov of Moscow presented a paper discussing the possibilities of a controlled thermonuclear reaction in a high current gas discharge. Some of the conditions necessary for the achievement of an efficient fusion reactor are qualitatively reviewed and the Russian experiments are discussed in the light of these conditions.*

*It is concluded that the Russian work is a first step on the long road to controlled thermonuclear power but extension of these experiments to higher powers cannot lead to a practical solution. The scientific results however, are of great interest and may lead to a better understanding of the mechanism of cosmic ray production.*

*L'ACADÉMICIEN KOURTCHATOV de Moscou a présenté récemment à Harwell une communication sur la possibilité d'obtenir une réaction thermonucléaire dirigée dans une décharge à gaz de haute intensité. On passe en revue les conditions nécessaires pour obtenir un réacteur à fusion à bon rendement et l'on discute les expériences russes de ce point de vue.*

*On conclut que les travaux russes présentent le premier pas sur la longue voie vers l'énergie thermonucléaire dirigée, mais que l'agrandissement de ces expériences dans la direction des énergies plus grandes ne peut pas conduire à une solution pratique. Néanmoins, les résultats scientifiques de ces travaux offrent un grand intérêt et vont peut-être mener à une meilleure compréhension du mécanisme de la production des rayons cosmiques.*

*AKADEMIKER KURTSCHATOW von Moskau hat neulich in Harwell einen Vortrag über die Möglichkeit einer gesteuerten thermonuklearen Reaktion in einer Gasentladung hoher Stromstärke gehalten. Eine qualitative Übersicht einiger Bedingungen, die zur Erzielung eines leistungsfähigen Kernverschmelzungsreaktors unentbehrlich sind, wird gegeben, und die russischen Experimente werden im Lichte dieser Bedingungen erörtert.*

*Man schliesst daraus, dass die russische Untersuchung den ersten Schritt auf dem langen Wege zur gesteuerten thermonuklearen Energie quelle darstellt, dass aber durch Ausdehnung dieser Experimente zu grösseren Energiewerten keine praktische Lösung erzielt werden kann. Doch sind die wissenschaftlichen Ergebnisse äusserst interessant und können dieselben zu einem besseren Verständnis des Mechanismus der Entstehung kosmischer Strahlen führen.*

*EN UNA RECIENTE CONFERENCIA pronunciada en Harwell, el académico Kurchatov de Moscú, discutió el tema de las posibilidades de una reacción termonuclear controlada en una descarga gaseosa de alta corriente. Son examinadas cualitativamente varias de las condiciones necesarias para lograr un eficiente reactor de fusión y se analizan los experimentos rusos con relación a tales condiciones.*

*Se llega a la conclusión de que los trabajos rusos representan el primer paso en el largo camino hacia una energía termonuclear controlada, pero la extensión de estos experimentos a potencias más elevadas no puede conducir a una solución práctica. No obstante, los resultados científicos ofrecen gran interés y pueden dar lugar a una mejor comprensión del mecanismo de la generación de rayos cósmicos.*

*АКАДЕМИК КУРЧАТОВ из Москвы прочел недавно в Харвелле лекцию о возможности осуществления управляемой термоядерной реакции в газовом разряде высокого тока. Некоторые из условий, необходимых для осуществления производительного термоядерного реактора, рассматриваются в качественном отношении; русские опыты обозреваются с точки зрения этих условий.*

*Делается вывод, что русское исследование является первым шагом на длинном пути к управляемому источнику термоядерной энергии, хотя и увеличение энергетического масштаба этих опытов не может привести к практическому решению. Тем не менее полученные научные результаты весьма интересны и могут привести к лучшему пониманию механизма образования космических лучей.*

1 This lecture is reported in a slightly abridged form in Engineering (London), vol. 181, pp 322-5. May 11, 1956. See also Nucleonics June 1956

2 G. Cillie, Mon. Not. Roy. Astr. Soc, pp 92, 820. 1932

3 G. Gamow and C. L. Critchfield, Theory of Atomic Nucleus and Nuclear Energy Sources, Oxford University Press, p 267. 1949

4 S. W. Cousins, A. A. Ware, Proc. Phys. Soc., pp 64, 159. 1951

5 A report, of observations following a recent solar flare by a number of authors, is published in The Journal of Atmospheric and Terrestrial Physics, vol. 8, no. 4/5, p 274, May 1956

6 L. Spitzer, Mon. Not. Roy. Astr. Soc. (London), pp 100, 396, 1940. See also L. Spitzer, Physics of Fully Ionised Gases. Interscience 1956. p 80

**If this radiation is absorbed and emitted many times within the gas then conditions approaching thermodynamic equilibrium would develop, and the gas will radiate as a black body. These conditions are presumed to exist in stars where the central temperature is usually many orders of magnitude higher than the surface temperature and energy flows to the surface by radiative transfer, convection and other processes. Steady state conditions are only possible because of strong gravitational forces and these are not available in terrestrial experiments.**

**In a controlled thermonuclear apparatus the gas must be prevented from dispersing by forces other than those of gravitation and because of the enormous gas pressures involved the particle density must be maintained at a level so low, that the mean free path for radiation absorption is much greater than the dimensions of the gas. Under these conditions the reaction need not be too explosive even if the reaction products are trapped and can be made to heat the gas.**

### 3. The temperature required

**The radiation from a completely ionised gas arises from the perturbation of electron trajectories by the coulomb field of positive nuclei and is often referred to a *bremsstrahlung*. The rate $W_r$, at which energy is radiated by a low density completely ionised gas has been investigated theoretically by Cillié[2] and is given by**

$$W_r = 1{\cdot}42 \times 10^{-34}\ n^2_2\ Z^3\ T_1^{\frac{1}{2}}\ \text{watts cm}^{-3},$$

**where $T_1$ is the kinetic electron temperature, $n_2$ the positive ion density and $Z$ is the atomic number of the ions. The electron density is closely equal to $Zn_2$.**

**The nuclear energy yield from a gas in which the ion temperature is $T_2$ depends, of course, on the nuclear reaction under consideration.**

**The rate $W_n$ at which nuclear energy is released by the gas is given by an expression of the form**

$$W_n = n^2_2\ f(T_2)\ E,$$

**where $f(T_2)$ is a function of temperature and the nuclear parameters only and $E$ is the energy released per nuclear event. Gamow and Critchfield[3] have calculated the energy yield for the D-D reaction and a similar calculation has been made for the D-T reaction.**

**For the rate of nuclear energy release $W_n$ to just exceed the radiated energy $W_r$, the temperature must be about $10^8$ °K for the D-D reaction and $3 \times 10^7$ °K for the T-D reaction. It is assumed that $T_1 = T_2$.**

**The D-D temperature is based on the assumption that tritium, which is a by-product of the D-D reaction, can be "burnt" and contributes to the energy yield of the D-D reaction giving 25 MeV per D-D neutron.**

**Since tritium is not a naturally occurring isotope of hydrogen it must be "bred" by utilising the neutrons from the T-D reaction. This can be done by capturing them in naturally occurring $Li^6$ which then breaks up yielding helium and the required tritium. The resulting energy yield is 22 MeV per T-D neutron. To maintain equal concentration of tritium and deuterium (*i.e.* a maximum reaction rate) every neutron must be captured in this way. In**

practice this is impossible, some are inevitably lost. The small deficiency can be made up, however, by utilising the neutron multiplication which takes place when fast D-T neutrons are incident on natural uranium. The amount of uranium required is very small. Because of the long range of fast neutrons this "breeding" process can, of course, take place at some distance from the hot gas and the tritium fed back into the gas as required.

If the necessity for conversion of the heat output (nuclear energy yield plus radiated energy) into electrical energy is taken into account the ratio of output to input energy can never exceed about 50. The necessity for utilising the hydrogen isotopes is now apparent. The $Z^3$ factor in the expression for the radiation loss means a much greater radiation loss for heavier elements which in any case have a lower reaction cross-section.

The temperatures quoted above are a lower limit since they are based on the assumption that only radiation escapes. Transfer of energy to the surrounding medium by the charged particles of the hot gas will be far from negligible and must be less than $50\ W_r$ if a power gain is to be achieved.

The above results can be summed up as follows. Energy must be delivered to a mixture of hydrogen isotopes to heat them up to a temperature exceeding $3 \times 10^7$ °K. The "fuel" must be maintained at the required temperature for a time sufficient for an appreciable fraction of the fuel to be burnt and during this time energy loss, by the escape of charged particles, must be reduced to a level such that it does not greatly exceed the inescapable radiation loss. It is the suppression of this conduction loss which is the central problem of controlled thermonuclear research.

### 4. The Russian experiments

To raise a gas to a high temperature it must be either placed in contact with (or exposed to the radiation of) a high temperature source or some form of ordered energy must be used, for example, electrical or mechanical energy. In the Russian experiments deuterium gas was heated by passing through it an electrical current of the order of one million amperes. This large current serves two purposes (a) to heat the gas, and (b) to prevent the radial escape of charged particles by the accompanying intense magnetic field. There is an expression known as the "pinch relation" which relates the sum of the mean kinetic temperature of the electrons and ions to the axial current $I$ (amperes) and the number $N_1$ of electrons per centimetre length of the current channel. For singly charged ions it is $T_1+T_2=3{\cdot}4\times 10^{13}\ I^2/N_1$. If radial pressure equilibrium had been achieved $T_1+T_2$ could be expected to exceed $10^7$ °K. The estimated temperatures were about $10^6$ °K implying that most of the kinetic energy of the charged particles was in ordered flow*. The time, of 10-20 microseconds, for which the current could be made to flow is not of sufficient duration for the transient collapse of the current channel to change into random motion of the charged particles. In one of the last paragraphs read by Kurchatov it is intimated that periods of time longer than 20 microseconds are necessary for steady state conditions to be approached. The type of experiment described in which electrodes are employed is not suitable for extension to longer current pulses. At the highest currents the apparatus was destroyed after each pulse and even if it were not the material of the electrodes would eventually contaminate the ionised deuterium. In discussion after his lecture, Academician Kurchatov indicated that work was proceeding on electrodeless ring discharges of the type investigated by Cousins and Ware[4].

Whilst the estimated temperatures were much less than those to be expected from the pinch relation neutrons were detected from the gas and what is of more scientific interest, high energy x-rays were emitted with an energy extending up to 400 KeV, even when the potential difference between the electrodes did not exceed 10 kilovolts. It follows that electrons of at least 400 KeV must have been present in the gas since the radiation could only be produced by electron-ion "collisions." Presumably the mechanism responsible for the acceleration of electrons to these high energies was also responsible for the accelerations of deuterons to energies where the nuclear reaction rate was appreciable. These experimental observations are of great interest, particularly to astrophysicists. They appear to demonstrate that electrons and ions can "runaway" in a non-steady state plasma, that is they gain more energy from an electric field than they lose in collisions. At the present time it is not clear how many electrons have high energies. A careful study of both the intensity and frequency distribution of the x-rays is necessary to settle this point.

It seems unlikely that potential differences of the required magnitude could exist in a conducting plasma. The accelerating electric field is more probably due to a rapidly varying magnetic field as in a betatron accelerator.

An increase in the intensity of low energy cosmic rays has been detected following a solar flare[5], and it is possible that conditions in a flare are sufficiently close to those described, for a similar particle acceleration mechanism to be operative.

### 5. Time constants

A considerable amount of energy has to be communicated to the gas to raise it to the required temperature. In general only a fraction of this energy is recoverable in a useful form. About 10 KeV per particle must be supplied initially both to electrons and nuclei, and two nuclei are lost for each disintegration. Assuming 10 MeV is released as heat per nuclear event then at least 1 per cent of the initial "fuel" present must be "burnt" during the cycle if the energy supplied to the gas is to be recovered. Probably 10 per cent is a more realistic guess. The question arises: how long must the gas be maintained at a high temperature for a 10 per cent burn up? Since the nuclear reaction rate is proportional to the square of the particle density, low density systems

* The method of temperature measurement used by the Russian experimenters did not distinguish between electrons and ions so that it is possible that the electron temperature far exceeded the ion temperature

will involve long times and high density systems short times. Although no particle densities were given for the Russian experiments they are probably of the order of $10^{18}$ per cubic centimetre, thus if $\sigma$ is the nuclear reaction cross-section, $n_2$ the density of nuclei, and $v$ the mean velocity, the average life time of a nucleus is $1/n_2\sigma v$. Taking $\sigma = 10^{-24}$, $cm^2$, $n_2 = 10^{18}$ $cm^{-3}$ and $v = 10^8$ $cm.sec^{-1}$ as representative figures the average lifetime is 0·01 second. The nuclei are assumed to have been raised to the required temperature instantaneously. It is known, however, that electrons gain energy from an electric field at a much greater rate than relatively heavy nuclei and therefore, if the only mechanism of energy gain by nuclei was electron-nuclear collisions, the time to raise the ion temperature could be quite long in a low-density gas. Using a formula derived by Spitzer[6] this time is estimated to be of the order 100 microseconds. The appearance of neutrons about 10 microseconds after the initiation of the discharge in the Russian experiments suggests a much more efficient mechanism of energy transfer to the heavy particles and it is therefore probable that a time lying between $10^{-3}$ and $10^{-2}$ seconds would be the longest required. Any mechanism which reduces the time for which these enormous currents must be made to flow, eases the technical problem of producing these currents. The experiments described by Kurchatov suggest that such a mechanism exists.

### 6. Conclusion

The Russian experiments described at Harwell represent a first attempt to establish controlled conditions under which a thermonuclear reaction might be expected. Provided steady state conditions had time to develop, gas temperatures of the right order of magnitude should have been attained. These conditions were not achieved because the duration of current flow was too short. The Russian workers are well aware of this limitation and are undoubtedly carrying out research to overcome it. The nuclear reactions which were detected, occurred at a rate too great to be accounted for by the estimated temperatures, and are attributed to some unexplained accelerating mechanism. The investigation of this mechanism will certainly occupy the time of many physicists, particularly those interested in the generation of cosmic rays.

This far-sighted work will undoubtedly go down in scientific history as the first demonstration of nuclear reactions in a gas discharge plasma but it must be emphasised that an enormous gap lies between this demonstration and the building of a thermonuclear reactor which produces more electrical power than it consumes, if indeed, this is possible at all.

I am very grateful to R. S. Pease for suggestions which have helped to clarify the text.

# Report from Vienna-I

***For the first time, atomic energy appeared on the agenda of the World Power Conference. A NUCLEAR POWER special correspondent covers the proceedings***

THE TECHNICAL SESSIONS of the World Power Conference held in Vienna between June 17th and 23rd were conducted in French, German and English. An interesting innovation for the simultaneous translation service lay in the provision of individual pocket-size radio sets with earphones. These could be tuned at will to any of these three languages.

The conference, which is held at approximately five-yearly intervals, covers the whole field of basic power generation, the preparation of fuels for this purpose, the compilation of statistics on production and utilisation and the study of the economics of power systems. The object, which is achieved to a very satisfactory extent, is the interchange of information and the identification and discussion of common problems between the power industries of the whole world. The number of participants—about 2,000—and the number of papers presented—nearly 300—reflect the breadth of interest and the firm establishment of the conference.

For the fifth conference, the chosen theme was *World energy resources in the light of recent technical and economic developments*. During the fourth conference, held in London in 1950, it had become clear that atomic energy would merit discussion at this present conference, but it was not possible at that time to judge the time scale applicable to this new power source. However, a great deal has happened in the meantime, technically, industrially and politically. The United Nations Conference at Geneva on Atomic Energy had shown to all how much there was to talk about and to a large extent how very much people, from all countries, were prepared to talk about their work. More important perhaps, was how much governments were prepared to allow them to talk.

### Developed and underdeveloped countries

In his speech during the opening ceremony, held in the magnificently rebuilt State Opera House, the President of the Austrian National Committee, Gen-Dir Franz Holzinger, drew attention to early Austrian contributions to nuclear physics, and mentioned particularly Professor Erwin Schroedinger who gave a special lecture for the occasion. Sir Harold Hartley, the President of the Conference, drew attention to the danger of an inbalance between the application of power to

industry in the highly developed countries, and the lack of availability of power for industry in those less highly developed. He expressed great expectations for the next sectional meeting in Jugoslavia which is to treat particularly of these questions. The Austrian Federal President, Dr. Theodor Körner, in officially opening the discussions said that Austria was making great efforts to upbuild her industry and to contribute to international cooperation in Europe, and he went on to say 'It is due to this hard and determined work that there are today no longer any doubts about Austria's ability to exist independently. Austria has become the second largest producer of crude oil in Europe, and it is the only country capable of making large-scale exports of electrical power—exports which will still gain in importance in the near future.'

### Rising fuel costs

Division I, Section A dealt with the development of national power economies from 1950 to 1954, and the general report disclosed a marked difference between certain of the highly industrialized countries which have practically completed the expansion of the power capabilities of their existing fuel supplies, and certain other countries or regions in which large-scale expansion can still take place. The cost of coal production is rising steadily in all reporting countries. This does not, however, include Russia or China which submitted no written reports, but it was stated in discussion that the USSR had planned a very considerable increase in coal output during the next five years, which can hardly be reconciled with rising costs. At the same time, it was stated that Soviet power output is to be increased by 120 per cent during the next five years, major contributions to this being from enormous hydroelectric plants now under construction in Siberia which will be associated with industries located nearby. A 900 kilometer, 400 kV transmission line was stated to be already in operation.

Owing to rising steel production throughout the world good coking coal is becoming increasingly scarce, so that much work on alternative coking techniques has had to be undertaken. In the USA at the present time coal is so plentiful that economic exploitation of seams more than 28 inches thick is said to be but 55 per cent of the coal content of the seam.

Petroleum in 1954 met nearly one-third of the world's energy requirements and it is of interest that the balance of production has changed noticeably since 1948, the USA, for instance, producing 58·5 per cent of the world's supply in 1948 but only 45·6 in 1954. Oil supplies from the Middle East increased, and new producers arose in Germany and Austria. Moreover, the relative consumption in the USA has decreased.

### Changing emphasis

Interesting information was tabled concerning electricity production and utilisation. A high rate of increase is found, of course, in countries undergoing marked industrial development but there is some evidence of saturation being reached in highly electrified countries. In Switzerland, for example, overall domestic demand already exceeds the overall industrial demand. At the present time electricity is a surprisingly small component of gross energy consumption—only about 5 per cent in Europe as a whole—but there is a remarkably high rate of increase of about 8 per cent. This is due partly to rising industrialization, living standards, and populations, and partly to the reassertion of demand by the war-damaged countries.

In so far as this demand is supplied by thermal stations, changes are occurring in the fuel supply to these stations, with an appreciable increase in the utilization of oil and gaseous fuel and, so far as coal is concerned, a marked decrease in the use of high-grade coals. In several countries with appreciable peat resources, this is being developed as a fuel for suitably designed power stations.

Hydroelectric projects show an increased tendency to the building of high-capacity reservoirs and also an

*"Nuclear energy has come at a most timely moment—it has multiplied the energy resources of the world manyfold" President Sir Harold Hartley told delegates to the Fifth World Power Conference assembled at the opening ceremony in the Vienna State Opera House on June 17th. At the closing session, Sir Harold, at the end of his term of office, handed over the presidency to Generaldirektor Dipl-Ing Franz Holzinger of Austria*

increase in the size of individual generator units—up to 165,000 h.p. for the Grand Coulee Francis turbines, and even more for the new Siberian developments.

It was not considered that any appreciable reduction in the cost of electricity produced by conventional means could be expected, and indeed there is a tendency to forecast a general rise in price.

The development of atomic power from the resources of uranium and thorium which are known to be considerable in comparison with the resources of combustibles and water power was here considered in general terms, and it was remarked that two schools of thought exist, one holding that depletion of exploitable resources of coal and petroleum is to be expected in 50-200 years, the other forecasting a considerably longer period. It was recognized, however, that the situation varies markedly from country to country.

### States' developing rôle

The British plan for a full-scale ten-year construction programme for nuclear power stations outlined in the White Paper, was described but it will not be given again here. Other possible contributors—solar energy, terrestrial heat, tides, wind power, and energy from sewage sludge—have been examined, and though each is certainly an available source of energy, they are not found to make a very appreciable contribution to the overall need.

As to organization, an increasing tendency for State participation in power undertakings was noticeable, quite irrespective of any policy intention to State Ownership or otherwise, while public bodies are having a very marked influence on the planning and location of plants.

Attention was drawn to the need for uniformity of usage in the presentation of information power production, and this was mentioned as a suitable task for the preparations for sixth world power conference.

### Fuel and power economics

The papers presented in Division I, Section B, dealt with the following subjects:

a. Statistics and assessment of water power resources
b. Advance planning of fuel and power supply and demand
c. Compilation of uniform and comprehensive world fuel and power statistics

Under the first heading were grouped papers which analyzed and criticized the statistical methods recommended for assessing the potential of power yield, both technically feasible and economically sound, for hydroelectric schemes, and attention was particularly drawn in the general report to the work of the Russian Hydro-Energy-Project Institute which has plotted the calculated gross potentials all over the world by a uniform system, and is now undertaking an analysis of the sources of loss. This survey shows particularly well the immense resources of the African and Asian river systems which are, moreover, relatively little exploited as yet.

Under the second heading were reviewed the statistical methods used for determining the nature and capacity of plant best set up to augment a power supply system of known characteristics faced by a demand for which records are available. It is stated that, in principle, all the existing theoretical problems in this field have been settled, though there is need for improvement in the completeness of the data which can be made available. Some usefulness is expected from the application of the most modern mathematical techniques. But it is pointed out very strongly that no such analysis can be satisfactorily extrapolated through major political or economic upheavals, nor through periods of decisive technical innovation. For a specific example, before 1914 the demand for coal had been increasing exponentially; after the war it remained practically constant. It is not clear, of course, to what extent the war alone was responsible for this. Economic crises, and the development of water power, oil exploitation and improvements in efficiency of fuel utilization probably all play their part.

In the third section, and in the major part of the discussion in this session, the difficulties and necessities for uniform preparation and handling of statistics were emphasized. It is clear that here there are exceptionally difficult problems and that we are not yet in sight of a comprehensive estimate of world fuel resources and requirements. The difficulty of comparing different forms of energy is quite fundamental.

Division II, Sections C, D, E and F dealt with the preparation, liquefaction and gasification of convention fuels and we shall not report here the discussion.

Division III, Section $G_1$, dealt with thermal power plants—general layout, design—and in the introduction to the general report it was stated 'current tendencies in the construction of thermal power plants, discussed in 28 pages on the subject reflect two prominent factors governing basic developments.

a. The steady, world-wide increase in energy consumption, continuing unabated since the Fourth World Power Conference, in 1950, and leading to the design of new power stations of every increasing capacity.
b. The shortage of fuel, especially of boiler coal, forcing efforts to improve the thermal efficiency of power stations.

The major part of the world's power supply derives from coal-fired stations and it is well worth-while to consider the sections which dealt with this type of plant fairly fully.

As a percentage of total coal production, the availability of high-grade boiler fuel is steadily decreasing, and this trend may be expected to continue. Thus, thermal power plants must make increasing use of high-ash coal, oil and gas. It is predicted that in Europe as a whole, so far as can be seen, electrical power needs will double in the next ten years, and although the water-power resources are not yet fully developed, the major part of this must clearly come from thermal power stations—a term which, of course, must include nuclear stations.

Reviewing progress in the design of condensing steam power plants, some interesting general remarks were made.

As a general rule, because of the greatly increased outputs called for, the major power stations are planned as steam plants, because of the very great output per unit which can be obtained from a steam turbine compared with any other thermal prime mover, including the gas turbine. Usually, too, the base load will be carried by the new stations, this being consistent with the greater unit sizes and higher efficiencies obtained in the newer plants. There are quite noticeable differences in practice as between the United States and Europe in plant design.

The total installed capacity in a single U.S. power plant has reached 1,400 MW, and while the unit capacity is 200 MW in the largest stations, single units as large as 340 MW are now being built with unit boilers. Every method is employed to raise the station efficiency, and attention is therefore paid to the following points:

1. The highest attainable temperatures and pressures
2. The use of multiple reheat
3. Bled steam feed-water heating
4. The highest attainable vacuum

and these tendencies are carried to lengths much greater than those in vogue in Europe at present.

The highest steam conditions so far used are 650°C, 350 atmospheres (1,200°F, 5,000 lb/in.) generated in a Sulzer-type monotube boiler delivering 900 tons an hour. Boilers rated up to 170 atmospheres are normally of the vertical tube, natural circulation type; above this, forced circulation is used. Austenitic steels are used for these high-temperature applications.

### European trends

In Europe, the largest set in actual operation at present develops 150 MW while the CEA plant now under construction at High Marnham with five 200 MW units will be comparable in total output with the larger U.S. plants. There has remained, in general, in public utility plants, a strong tendency to use ferritic steels and accept that, in consequence, steam temperatures must not exceed 530° (985°F).

It was stated that the forced-circulation monotube boiler, such as the Sulzer or the Benson, is becoming increasingly used—particularly in German practice. It is recognized that plants with higher steam conditions (above 600°C or 1,110°F) have given good results in industrial use and it is anticipated that future design for public utilities will be influenced by this experience.

Regarding thermal efficiency, it was recalled that at the beginning of the century, efficiencies were around 8-9 per cent; at present, the most advanced plants are reaching 40 per cent. It is particularly interesting to note that at the time of the Fourth Conference the best recorded efficiency was 33·5 per cent and thus an improvement of nearly 20 per cent in actual efficiency is claimed during this period. It must be recognized, however, that the 'normal' efficiency of power generation for power systems as a whole nowhere approaches these figures which relate only to the newest plants at the peak of their performance. However, some notable improvements in cycle efficiency must be acknowledged.

For large units, it was explained in the general report that the heat required per kWh output can be reduced from 2,700 to 2,500 kcal by modifying the turbine stop valve conditions from 500°C (930°F) to 600°C (1,110°F) with a corresponding pressure change from 1,142 to 2,000 lb./in. gauge, retaining the exhaust wetness at 14 per cent, which was declared as the maximum permissible.

The use of reheat during the expansion of the steam in the turbine (for which purpose it may be withdrawn, heated, and fed back into the turbine) removes the restrictive influence of the permissible exhaust wetness by drying the steam. In fact the effect of reheat was stated to be twofold:

1. A slight increase in output when the enthalpy drop is carried out in stages because of the form of the steam chart and a consequent slight increase in enthalpy drop with increase in entropy.
2. An improvement in efficiency of expansion in the later stages of the turbine due to the lower wetness. Energy must, of course, be supplied in the reheat process, but when this is set off against the credits there remains a worthwhile net gain in efficiency.

The use of bled-steam feed-water heating is simpler to apply than reheat and is a generally accepted method of distorting the Rankine cycle to approximate more closely to the Carnot cycle. The theoretical ideal is to bleed continuously, but when considering an increase in the number of bleed points the gains in efficiency are subject to diminishing returns and thus now not more than 7-9 stages are employed.

If the number of reheat stages is taken as two then it will be found that the best pressures for inlet temperatures above 600°C (1,110°F) are above the critical pressure. Three such plants are either under construction or in operation in the U.S. with the following particulars:

| output MW | inlet atm | pressure lb/in.² gauge | inlet temperature °C | °F | reheat stages |
|---|---|---|---|---|---|
| 325 | 351 | 5,000 | 648 | 1,200 | 2 |
| 125 | 316 | 4,500 | 621 | 1,150 | 2 |
| 250 | 246 | 3,500 | 594 | 1,100 | 2 |

Of these, the 325 MW plant should show an efficiency of 40 per cent.

Since it seems fundamental that most of the rewards from improvements to the form of the thermodynamic cycle are embodied here, further improvements in thermal efficiency must come, in the future, from the employment of higher inlet steam temperatures, involving the use of improved high-temperature-resistant alloy steels. This is so if we exclude a radical increase in the number of points of application of reheat during the expansion of the steam through the turbine.

*to be continued*

*THE MECHANICS OF ELASTIC SCATTERING assume that the neutron and the nucleus can be treated as elastic spheres and that the ordinary laws of mechanics hold. A transformation is made from the laboratory system of coordinates to one based on the centre of gravity of the particles and on the assumption that scattering is isotropic. In the latter system some important results are obtained. The average energy loss per collision is discussed and an expression derived for the number of collisions to slow down. When more than one type of atom is present in a medium the average logarithmic energy loss and the average cosine of angle of scatter in the laboratory system of the elements have to be combined.*

*ON FAIT UNE SUPPOSITION dans la mécanique de la dispersion élastique que le neutron et le noyau peuvent être traités comme des sphères élastiques et que les lois ordinaires de mécanique y sont valables. On transforme les système des coordonnées de laboratoire en un système basé sur le centre de gravité des particules et sur la supposition que la dispersion soit isotropique. Quelques résultats importants ont été dérivés dans ce nouveau système. On discute la perte moyenne d'énergie par collision et l'on déduit une expression pour le nombre de collisions produisant le ralentissement. S'il y a plus d'un type d'atomes dans le milieu, la perte logarithmique moyenne d'énergie doit être traitée ensemble avec le cosinus moyen de l'angle de dispersion dans le système des coordonnées de laboratoire.*

*MAN NIMMT IN DER MECHANIK der elastischen Streuung an, dass das Neutron und der Atomkern als elastische Kugeln angesehen werden können, wobei die üblichen Gesetze der Mechanik gültig sind. Es wird eine Transformation vorgenommen von dem Laboratoriums-Koordinatensystem zu einem System, welches auf dem Schwerpunkt der Teilchen sowie auf der Annahme der Streuungsisotropie basiert. Einige wichtige Ergebnisse werden im neuen System erhalten. Der durchschnittliche Energieverlust pro Zusammenstoss wird erörtert, und es wird ein Ausdruck für die Anzahl der verzögernd wirkenden Zusammenstössen hergeleitet. Wenn das Medium Atome von mehr als einer Art enthält, ist es nötig den durchschnittlichen logarithmischen Energieverlust zusammen mit dem durchschnittlichen Kosinus des Streuungswinkels in dem Laboratoriums-system der Elemente zu berücksichtigen.*

*LA MECÁNICA DE LA DISPERSIÓN ELÁSTICA supone que el neutrón y el núcleo pueden considerarse como esferas elásticas y que las leyes corrientes de la mecánica tienen aplicación. Se realiza una transformación del sistema de coordenadas de laboratorio a otro basado en el centro de gravedad de las particulas y en la hipótesis de que la dispersión es isotrópica. Con este último sistema se obtienen varios resultados importantes. El promedio de la pérdida de energía por colisión es discutida, y se deriva una expresión con respecto al número de colisiones para la retardación. Cuando en un medio se hallan presentes más de un tipo de átomo, deben combinarse el promedio de la pérdida logarítmica de energía y el coseno medio del ángulo de dispersión en el sistema de laboratorio de los elementos.*

*В МЕХАНИКЕ УПРУГОГО рассеяния делается предположение, что нейтрон и атомное ядро можно считать упругими шарами и что обыкновенные законы механики находят здесь применение. Проводится переход от лабораторной системы координат к системе, основанной на центре тяжести частиц и на предположении изотропии рассеяния. В новой системе были получены некоторые важные результаты. Обсуждается средняя потеря энергии на столкновение, а также выводится выражение для числа столкновений, вызывающих замедление. Когда среда содержит более одного рода атомов, нужно в лабораторной системе принимать во внимание среднюю логарифмическую потерю энергии вместе со средним косинусом угла рассеяния.*

# Reactor Physics-4

## 1. Elastic collisions of a neutron with a nucleus

It was seen in the first article that the method by which fast neutrons were slowed down to thermal energies was to allow them to collide with the nuclei of light molecules. It is, therefore, necessary to start the discussion of the general problem of neutron slowing down by considering the mechanics of the collision between a neutron and a nucleus.

The model which is assumed for this discussion is that the neutron and nucleus can be treated as elastic spheres and that the ordinary laws of mechanics hold. Then the problem can be represented by the diagram in Figure 4.1 where for convenience the nucleus is supposed at rest. The neutron velocity relative to the nucleus is $v_0$ before the collision and $v_1$ after the collision, the direction of motion of the neutron then making an angle $\Psi$ with its original direction.

The coordinate system shown in Figure 4.1 is known as the laboratory system of coordinates.

However, for present purposes it is more convenient to change the system of coordinates to one in which the centre of gravity of the system is assumed at rest. This is illustrated in Figure 4.2.

If we use mass units, taking the neutron mass as unity and the nuclear mass as $A$, then in the laboratory system, if the velocity of the centre of gravity is $v_g$, then from conservation of momentum

$$v_0 = (1 + A)\, v_g \tag{4.1}$$

Thus, in the centre of gravity system with the centre of gravity reduced to rest, the neutron velocity $V_0$ will be given by

$$V_0 = v_0 - v_g = \frac{A v_0}{1 + A} \tag{4.2}$$

Now, in the laboratory system the nucleus was assumed at rest and so in the C.G. system the nucleus will have the velocity of the C.G. and so

$$V_2 = v_g = \frac{v_0}{1 + A} \tag{4.3}$$

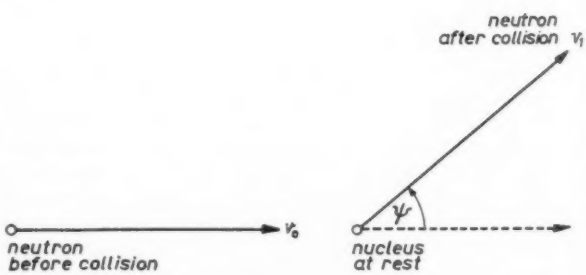



**Fig. 4.1** ***the laboratory system of coordinates***

*This instalment of NUCLEAR POWER'S basic course deals with neutron slowing down*

by James F. Hill *Senior Lecturer, Reactor School, Harwell*

In the C.G. system momentum must also be conserved and therefore the neutron and nucleus after collision must move along the same line in order that the C.G. remains stationary. Also, then

$$V_1 = AV_3 \tag{4.4}$$

For conservation of kinetic energy in the C.G. system

$$\frac{1}{2}V_0^2 + \frac{1}{2}AV_2^2 = \frac{1}{2}V_1^2 + \frac{1}{2}AV_3^2 \tag{4.5}$$

and using (4.2) and (4.3) this gives

$$\frac{Av_0^2}{1+A} = V_1^2 + AV_3^2 \tag{4.6}$$

Then from (4.4) and (4.6)

$$V_3 = \frac{v_0}{1+A} \tag{4.7}$$

and

$$V_1 = \frac{Av_0}{1+A} \tag{4.8}$$

From (4.2) and (4.8), and (4.3) and (4.5) it is seen that in the C.G. system there is no change in velocity of either the neutron or nucleus on collision.

It is now possible to draw a triangle of velocities for the neutron velocities in the two systems. This is done by saying that the neutron velocity after collision in the laboratory system can be compounded of the velocity of the centre of gravity and the neutron velocity after collision in the C.G. system. This is illustrated in Fig. 4.3.

Using the cosine rule in the above figure

$$v_1^2 = \frac{v_0^2}{(1+A)^2} + \frac{A^2v_0^2}{(1+A)^2} + \frac{2Av_0^2}{(1+A)^2}\cos\theta$$

$$\therefore \frac{v_1^2}{v_0^2} = \frac{1+2A\cos\theta+A^2}{(1+A)^2} \tag{4.9}$$

If the energy of the neutron in the laboratory system is $E_0$ before collision and $E_1$ after collision, then (4.9) can be rewritten as

$$\frac{E_1}{E_0} = \frac{1+2A\cos\theta+A^2}{(1+A)^2} \tag{4.10}$$

The maximum value of this expression is obtained by putting $\cos\theta = 1$, and so

$$\left(\frac{E_1}{E_0}\right)_{\max} = 1 \tag{4.11}$$

This corresponds to the case of $\theta = 0$, that is, a glancing collision and the neutron loses no energy.

The minimum value of $E_1/E_0$ is when $\cos\theta = -1$, that is, a head on collision where $\theta = \pi$, and then

$$\left(\frac{E_1}{E_0}\right)_{\min} = \left(\frac{A-1}{A+1}\right)^2 = \alpha \tag{4.12}$$

Thus $1 - \alpha$ is the maximum fractional energy loss of a neutron on collision. Also from (4.12) it can be seen that $\alpha$ is zero for the case of hydrogen where $A = 1$, that is a neutron can give up all its energy in one collision to a hydrogen nucleus. As $A$ increases the maximum fraction of its energy which a neutron can give up to a nucleus decreases as $\alpha$ increases becoming closer to unity the larger $A$ becomes.

## 2. Law of neutron scattering

It is not possible to proceed further until some assumption has been made about the way in which neutrons are scattered, that is, to state what is the neutron distribution as a function of angle after scattering. The appropriate law is found by experiment and is, that for the range of neutron energies with which we are concerned here the scattering is isotropic in the centre of gravity system. In other words, measured in the C.G. system a neutron is equally likely to be scattered in any direction. This means that $\theta$ is equally likely to have any value. Then the chance $p(\theta)\,d\theta$ that a neutron is scattered in the element of angle $d\theta$, lying between $\theta$ and $\theta + d\theta$ is given by taking the ratio of the conical element of

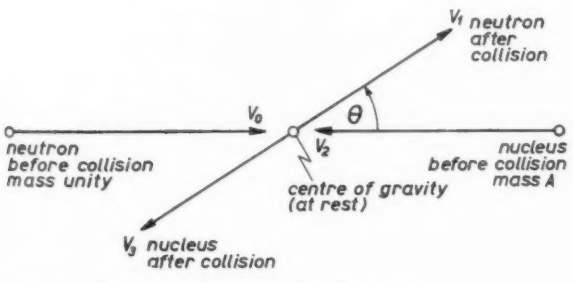



**Fig. 4.2** ***the centre of gravity (mass) system of coordinates***

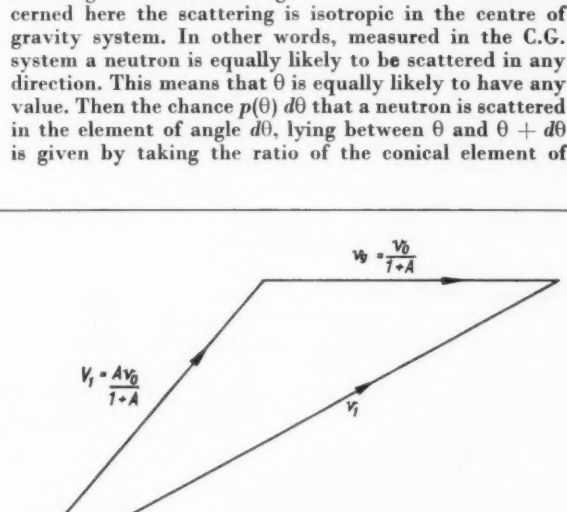



**Fig. 4.3** ***compounding of neutron velocities***

surface described on a sphere by the element of angle $d\theta$, to the surface of the sphere, and so

$$p(\theta)d\theta = \frac{2\pi \sin\theta\, d\theta}{4\pi} = \frac{1}{2}\sin\theta d\theta \qquad (4.13)$$

Then the chance of a neutron of initial energy $E_0$ being scattered into the energy interval $dE$ between $E$ and $E + dE$ is

$$p(E)dE = p(\theta)\frac{d\theta}{dE}\cdot dE$$

$$\therefore\ p(E)dE = -\frac{dE}{(1-\alpha)E_0} \qquad (4.14)$$

using (4.13), (4.12) and (4.10).

Now $dE$ must be negative as energy is lost by the neutron in the collision and so $p(E)dE$ is positive. Furthermore, and most important (4.14) shows that the chance of a neutron being scattered into any energy interval $dE$ lying in the energy range $E_0$ to $\alpha E_0$ is constant.

### 3. Average logarithmic energy loss per collision and number of collisions to slow down

It is now possible to calculate the average logarithmic energy loss per collision $\xi$ defined by

$$\xi = \left(\ln\frac{E_0}{E_1}\right)_{\text{average}} \qquad (4.15)$$

This is, using (4.14), (4.11) and (4.12)

$$\xi = \int_{\alpha E_0}^{E_0} \ln\frac{E_0}{E}\cdot p(E)dE \Big/ \int_{\alpha E_0}^{E_0} p(E)dE \qquad (4.16)$$

Now $\int_{\alpha E_0}^{E_0} p(E)dE = 1$, and substituting from (4.14) into (4.16) leads to

$$\xi = 1 + \frac{\alpha}{1-\alpha}\ln\alpha$$

$$= 1 - \frac{(A-1)^2}{2A}\ln\frac{A+1}{A-1} \qquad (4.17)$$

It is convenient to use an approximate value for $\xi$ for large values of $A$, and from (4.17) for large $A$

$$\xi \simeq \frac{2}{A + 2/3} \qquad (4.18)$$

In the case of graphite for which $A = 12$, both (4.17) and its approximate form (4.18) give $\xi = 0{\cdot}158$. Thus (4.18) is a sufficient good approximation for values of $A > 10$.

The number of collision $N_s$, required to slow a neutron down from an initial energy $E_0$ to an energy $E$ is defined to be

$$N_s = \frac{\ln\left(\frac{E_0}{E}\right)}{\left(\ln\frac{E_0}{E1}\right)_{\text{average}}} \qquad (4.19)$$

which from (4.15) becomes

$$N_s = \frac{1}{\xi}\ln\frac{E_0}{E} \qquad (4.20)$$

The value of $N_s$ of particular interest is that which gives the number of collisions to slow a neutron down from fission energy, taken as 2 MeV to thermal energy of 0·025 eV. In this case

$$N_s = \frac{1}{\xi}\ln\frac{2\times10^6}{0{\cdot}025} = \frac{18{\cdot}2}{\xi} \qquad (4.21)$$

### 4. The average cosine of the angle of scattering in the laboratory system

In correcting the expression obtained for the neutron current in (2.32) the quantity $\bar{\mu}$ was introduced, and this was, in fact, the average cosine of the angle of scattering in the laboratory system. We are now able to find in terms of $A$. For referring again to Figure 4.3, we see that

$$v_1\cos\Psi = \frac{V_0}{1+A} + \frac{Av_0}{1+A}\cdot\cos\theta$$

and so using (4.9)

$$\cos\Psi = \frac{1 + A\cos\theta}{1 + 2A\cos\theta + A^2} \qquad (4.22)$$

Now $\Psi$ is the angle of scatter in the laboratory system,

$$\therefore\ \bar{\mu} = (\cos\Psi)_{\text{average}}$$

and so, using (4.13)

$$\bar{\mu} = \frac{1}{2}\int_0^{\pi} \frac{\sin\theta\,.\,(1 + A\cos\theta)}{1 + 2A\cos\theta + A^2}\cdot d\theta$$

$$\therefore\ \bar{\mu} = \frac{2}{3A} \qquad (4.23)$$

### 5. The values of $\xi$ and $\bar{\mu}$ for mixtures of atoms

In the case in which more than one type of atoms is present $\xi$ and $\bar{\mu}$ have to be averaged over the different types of atoms. This is done by weighting with the scattering cross-sections, so that for a mixture of atoms we get

$$\xi = \Sigma_i N_i\sigma_s(i)\ \xi_i \Big/ \Sigma_i N_i\sigma_s(i) \qquad (4.24)$$

and

$$\bar{\mu} = \Sigma_i N_i\sigma_s(i)\ \bar{\mu}_i \Big/ \Sigma_i N_i\sigma_s(i) \qquad (4.25)$$

where the $N_i$ are defined as above.

Strictly the scattering cross-section in (4.24) and (4.25) should be averaged over the range of energy of the slowing down of neutrons.

As a consequence of (4.25), (3.24) can also be written as

$$\lambda_t^{-1} = (1 - \bar{\mu})\ \Sigma_i N_i\sigma_s(i) \qquad (4.26)$$

where $\bar{\mu}$ is the average value for the mixture of atoms.

| element | mass number | $\xi$ | $N_s$ from 2 MeV to 0.025 eV | $\alpha$ | $\bar{\mu}$ |
|---|---|---|---|---|---|
| H | 1 | 1 | 18.2 | 0 | 0.667 |
| D | 2 | 0.725 | 25.1 | 0.111 | 0.333 |
| Be | 9 | 0.207 | 87.9 | 0.640 | 0.0741 |
| C | 12 | 0.158 | 115 | 0.716 | 0.0556 |
| O | 16 | 0.120 | 152 | 0.779 | 0.0417 |
| U | 238 | 0.00838 | 2172 | 0.983 | 0.00820 |

**Table 3.2** ***Slowing down properties of some nuclei***

*The next article will deal with the derivation of the Fermi age equation*

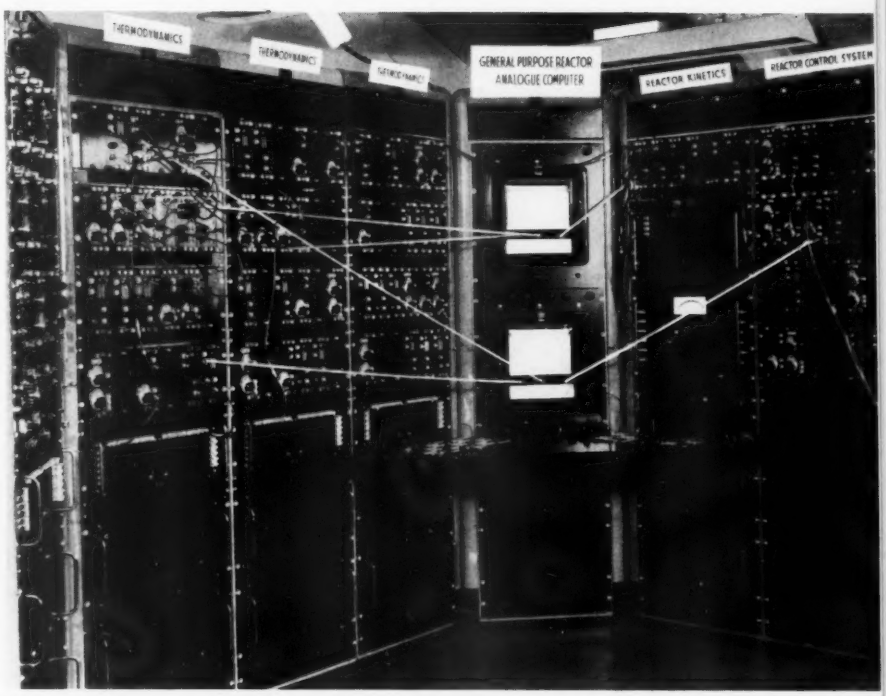
# Harwell simulator includes power plant sections

The determination of the transient response of a nuclear reactor and its associated power plant cannot often be obtained by direct analysis and it is usual in such circumstances to employ analogue computers for the solution of the several simultaneous equations involved. Analogue computers specially designed for studying nuclear reactor design problems are called reactor simulators and a number of machines of this kind are already in use in this country.

A simulator of a very simple type was shown at the recent Physical Society Exhibition and is in use at the UKAEA Reactor School for demonstration purposes. This equipment like the majority of the others available at the present time is suitable for rather limited studies of nuclear reactor kinetics and control systems. However, a much more ambitious simulator has been completed recently at the Atomic Energy Research Establishment and was demonstrated at Harwell during the recent Open Days. It is capable of much more comprehensive investigations than earlier equipments, particularly in connection with the study of nuclear power problems.

The new simulator as demonstrated is shown in the illustration. It is built on the unit principle and comprises three different sections at present, but a fourth section is to be added later. These are: (i) the section simulating the basic kinetic equations of the reactor, involving both the prompt and delayed neutron lifetimes; (ii) the control system simulating the behaviour of the electronic amplifiers and the control servo mechanisms; (iii) and (iv) the thermal sections simulating the effect of all temperature changes in the various components of the reactor, *e.g.* fuel, coolant and moderator, the transfer of heat to the coolant, the time delays in coolant circulation and the transfer of heat through the heat exchanger. The simulator is designed so that it may be extended to simulate the turbo-generator and its connection to the external load

The range of power level in a nuclear reactor from shut-down to full power may be very large and is often as much as 10 decades; for an analogue computer to simulate a reactor start-up, its output must vary over the same range. This is difficult to achieve and in the new Harwell simulator a limited performance is accepted covering four decades using vibrator-stabilized d.c. amplifiers, but increased range can be obtained by clamping all voltage after a $10^4$ excursion, resetting to $1/10^4$ of the values reached and continuing the run. This technique has actually been used on an earlier computer, but re-clamping was necessary after only one decade excursion.




***Designed to simulate the performance of a complete nuclear power plant, the new analogue computer was shown at the Harwell Open Day. In this view, three complete sections are seen: a fourth is to be added later***

There is no fixed circuit arrangement in the computer, but forty unit amplifiers and twenty coefficient units are available which may be interconnected as required to set up the required equations. There are in addition, a number of servo-multiplier units which can be used to give coefficients which vary with time, etc.

As can be seen from the illustration, the simulator is provided with a control desk which has various input-output sockets. Interconnection of these allows the various equations to be set up according to the required initial conditions. Recorders (there are 8 recorders in the computer) can also be connected to record the desired information.

At the Harwell Open Day a demonstration was given to show the effect of an increase in the demanded power on the control rod position, and plots were obtained of the change of power with time, change of control rod position with time, and change of temperature of coolant, fuel and moderator with time. It was noted that initially the control rod moved out rapidly and as the power reached the new demanded level the control rod moved back to its original position which it would reach in the absence of any thermal effects. In this case however the rapid increase in the fuel temperature and the slower increase in the moderator temperature caused a fall in reactivity and the control rod had to move out and reached a final steady position only when the moderator temperature had reached equilibrium.

Apart from studies of this kind it is understood that it will be possible to study the stability and optimum design of the overall control system of a reactor with the new simulator, that it will be possible to evaluate the consequences of a wide variety of fault conditions and thereby consider the advantages of alternative designs, and that it will also be possible to replace sections of the simulator by components of the reactor proper (*e.g.*, the control rods and driving amplifiers). This latter facility will be very useful in functional testing of components in advance of the completion of the reactor.

# Vacuum furnace sinters, melts, casts—up to 1800°C

Vacuum casting techniques have been used since the first world war but are now developing rapidly to meet the needs of nuclear power and other industries. Typical of the smaller laboratory-type of equipment for vacuum metallurgy is the ½ lb (0·23 kg) capacity vacuum furnace by Efco-Edwards Vacuum Metallurgy Ltd.

This is resistance-heated, and with the re-crystallized alumina refractory materials supplied as standard is suitable for sintering, melting and casting up to a temperature of 1700°C with 1800°C possible for short periods, thus being suitable for the majority of metals and alloys to be treated in this way. Provision is made for working in different atmospheres and suitable controls and sight glasses are fitted to allow full supervision of the melt.

The furnace proper is mounted on a fully self-contained and mobile pumping unit consisting of vapour and mechanical pumps, vacuum gauge and full valving and safety features. This pumping unit without the furnace is adapted for a multitude of high vacuum pumping duties and being castor-mounted can be readily transferred from place to place.

Electrical supplies are brought to the furnace from a separate power unit also castor-mounted.

A stainless steel furnace pot, suitable mould and ancillary apparatus are contained inside an electro-plated mild steel vacuum chamber. The furnace pot is 5½ in. (140 mm) diameter and 6 in. (152 mm) high and pivoted on a transverse shaft passing through the chamber wall via rotary vacuum seals, thus allowing the pot to be tilted up to 100° from the vertical by an external counter-balanced lever. A radiation shield assembly surrounds a 100 millilitre refractory crucible. The crucible is seated upon a refractory dish supported in turn by the base radiation shield stack. This refractory dish acts as a suitable container for the electrical resistance heating element, the top of the heating element being kept in place by a short length of refractory tubing. Current is supplied by two conductors diametrically opposed on the axis of the pot and located between the outer radiation shield and the inner surface of the pot. Flexible leads are taken from the bottom of the furnace pot to two Edwards Type 9 water-cooled and vacuum-sealed electrodes in the chamber lower wall. These leads allow the furnace pot to tilt with a minimum of friction. Slight tilting of the pot can also be used to make small quantity alloy additions to the crucible from a chute at the top of the pot.

A mould is pivoted from two hooks on the top edge of the furnace and is positioned to allow pouring of molten metal from the crucible into the centre of the mould. When the furnace pot is tilted for pouring, the mould, as it is hanging free, always remains vertical. A small refractory channel, bridging the gap between the crucible and the pot wall acts as a splash shield. A stainless steel splash is also positioned against the chamber wall on the mould side and the pumping aperture at the base of the chamber is covered with gauze to prevent metallic particles entering the pump.

*By the newly-formed company Efco-Edwards Vacuum Metallurgy Ltd, this ½ lb vacuum furnace is resistance heated. It is shown here with the furnace pot tilted ready for pouring into the mould*

The entire furnace pot and mould assembly together with various protective shields are readily removable from the vacuum chamber for renewal or cleaning. The vacuum chamber is 12 in. (304 mm) diameter and 21¼ in. (540 mm) high from its bottom flange face. A lid with two lifting handles covers the top of the chamber and seats on an "O" ring sealed flange. The machined flanged sealing surface is protected by a projecting spigot when the cover is laid aside. There are two sight windows, one directly above the crucible facilitating temperature measurement by optical or total radiation pyrometers; the other gives a clear view of the casting operation.

A sliding rotary vacuum seal carries a vertical shaft through the lid and is used for lifting and revolving clear the top radiation shield assembly from the furnace pot. The shaft also controls a moveable shutter over the sighting windows to protect them from metal evaporation. Both lid and vacuum chamber are water-cooled, suitable rifled nozzles being provided for the connection of rubber hose.

# US-UK cooperation in bellows expansion joints

To meet the demands of the aircraft industry, both Teddington Aircraft Controls Ltd, of Merthyr Tydfil, and the Solar Aircraft Company of San Diego, USA, independently developed the manufacture of stainless steel bellows-type expansion joints. In each case the original applications were for jet engines, after-burners, and control systems, followed after a period of development by marine and industrial applications. Teddington and Solar now operate in technical collaboration, to their mutual advantage.

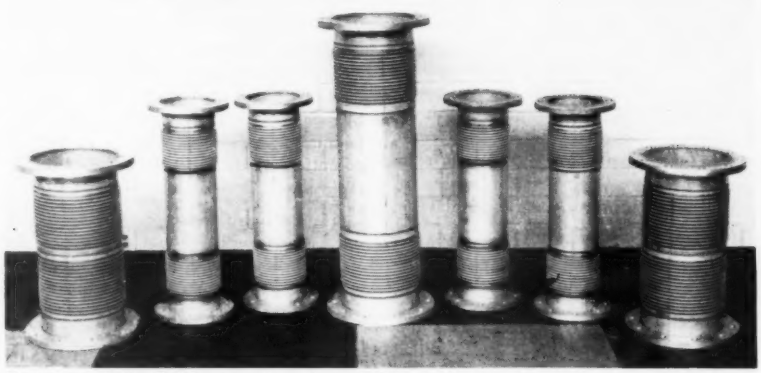
Teddington, pioneers themselves in the aircraft bellows field, set about adapting the expansion joints for various industrial uses such as temperature compensators, pressure - reducing valves, volume compensators, diesel exhausts, steam traps, thermostats and boiler uptakes. Their first products received an immediate response from industry, and bellows are now in use in gas turbines, diesel engines, laboratories and furnaces. Recently, Teddington Aircraft Controls received a request to make expansion joints for the Atomic Energy Authority. This order is considered by Teddington to be particularly significant, as they believe that there is a large and developing field for bellows in nuclear engineering.

A few months ago, Teddington Aircraft Controls, whose main works are at Merthyr Tydfil in South Wales, opened another factory at Ammanford for the manufacture of industrial bellows.

Thin-walled bellows are made from butt-welded stainless steel tubes, and are manufactured with internal diameters ranging from 1 in. to 84 in. The cold-rolled stainless steel sheet is of very uniform thickness, and the butt-welding process used to form the tube ensures that the weld matches the accuracy of the sheet. It also avoids the unequal stress characteristics inherent in bellows made from lap welded tube.

For high-pressure applications, much thicker-walled bellows are used. These are known as U-span and half-span types and are fabricated in annular sections which can be of very large diameter. The length of a bellows, and its convolution depth depend on the working conditions for which it is designed. As a general rule, the bellows length does not greatly exceed its inside diameter, although there are exceptions.

*Claimed to be the biggest yet, this 28 ft stainless steel expansion joint was made by Solar for a supersonic wind tunnel*



*British made by Teddington, these butt-welded, double ended stainless steel bellows assemblies are for marine diesel exhaust systems*

To ensure a smooth flow, the bellows are often fitted with an internal sleeve. Since they are made of stainless steel, they are exceptionally fatigue resistant and are able to withstand temperatures up to 800°C.

# New Noral alloy combines strength, lightness, conductivity

An interesting new aluminium alloy for busbars has recently become available. Given the designation Noral D50S by its makers, Northern Aluminium Company Ltd, the alloy combines strength with lightness and high current-carrying capacity. Noral D50S has physical properties such that, with the increase in size necessary to compensate for its lower conductivity compared with copper, busbars of this alloy are mechanically, as well as electrically, equivalent to their copper counterparts. Its minimum ultimate tensile strength is 13 ton/in², minimum 0·1% proof stress 10·5 ton/in², and its electrical resistivity 3·133 microhm/cm at 20°C (55% IACS). Being a fully-heat-treated magnesium-silicide alloy, its conductivity is lower than that of the aluminium of electrical purity hitherto generally used for busbars—the addition of any element to pure aluminium is bound to have this effect. Against this, however, must be counted the fact that its temperature coefficient of resistance (0.00364/°C) is lower than that of aluminium of electrical purity.

# Polarograph apparatus for analysis of trace elements

Polarography is a method of chemical analysis particularly adapted to the qualitative or quantitative determination of metallic and other reducible ions in solution. It can be applied to very small quantities of solution of very low concentration, and is therefore especially suited to the determination of trace elements.

The method is based on the electrolysis of a solution in a cell in which one electrode consists of minute mercury drops falling from a fine capillary tube, while the other electrode consists of a pool of mercury or a metal plate or wire.

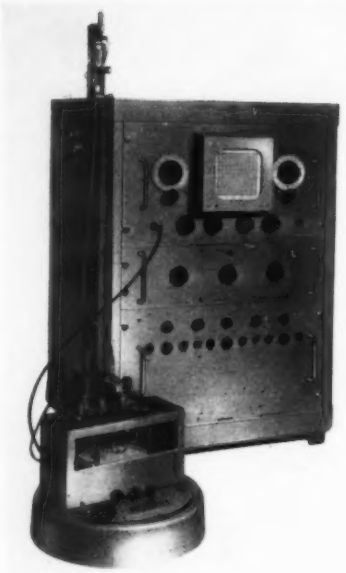
As the voltage across such a cell is slowly increased from zero, the current is at first very small, but begins to increase fairly rapidly when the decomposition potential of a reducible ion is reached.

On further increasing the voltage, the current at first continues to rise but finally settles down to a constant value which is proportional, other factors being constant, to the concentration of that particular ion. Thus, if the current is plotted against voltage, a step-like curve is obtained, known as the polarographic wave, or polarogram. The voltage at which the current reaches half its final value is known as the half-wave potential, and is characteristic of the particular ion. If a number of ions are simultaneously present and provided their half-wave potentials differ sufficiently, the polarogram will consist of a series of successive steps, from the heights of which the concentration of the individual ions may be determined.

In order to ensure the correct conditions in the cell, the solution must usually contain a relatively high concentration of a "supporting" electrolyte, and other substances may have to be added to inhibit spurious maxima in the curves. For further details reference should be made to a standard text-book.

The first polarograph was invented by Heyrovsky and Shikata in 1925 and employed a mirror galvanometer and photographic recording. The first fully successful cathode-ray polarograph was that developed by Randles and Airey at the Chemical Inspectorate, Woolwich Arsenal (M.O.S.). This instrument was further improved and simplified by H. M. Davis (British Patent No. 702685) and forms the basis of the K1000 instrument, which is being manufactured by Southern Instruments Ltd, Camberley, Surrey, under licence from the National Research Development Corporation.

In the K1000 instrument, the entire change of potential is effected during the lifetime of a single mercury drop, instead of being spread over the lives of many drops as in the conventional instrument. The potential sweep is applied through a load resistor in series with the cell by means of a compensation circuit which maintains a constant rate of change of potential across the cell, irrespective of the voltage drop in the load resistor.



*The K1000 polarograph by Southern Instruments is a productionised version developed under licence from the National Research Development Corporation*

The potential difference existing across the cell is amplified and applied to the X-plates of a long after-glow cathode-ray tube. The voltage appearing across the load resistor, which is proportional to the current flowing in the cell, is similarly applied to the Y-plates. The cathode-ray tube spot is thus caused to trace out the polarographic curve on the screen of the tube.

It is necessary to ensure that no major change in the surface area of the drop occurs during the potential sweep and also, in order to secure a reproducible trace, the sweep must commence at the same point in the life of each drop. These requirements are met by means of a triggered delay circuit, actuated by the fall of each drop, which delays the start of the next sweep until late in the life of the succeeding drop.

The polarographic method has found applications in all branches of research and analysis. This is indicated by the extent of the literature which now exceeds 3000 papers. These papers cover all fields associated with organic, inorganic, physical and biochemistry and with medicine. On the inorganic side a large number of elements can be estimated in concentration ranges from a fraction of 1 microgram to 3 milligrams per millilitre, the lower limits being more easily obtained by cathode-ray methods. The method finds its greatest application when one or more constituents or impurities are known to be present in a material in the known absence of interfering elements, or where simple procedures for overcoming interferences have been evolved. The following is a list of some of the more important elements that can be satisfactorily determined by the polarograph: aluminium, antimony, bismuth, cadmium, chromium, cobalt, copper, europium, fluorine (as fluoride), gallium, germanium, indium, iron, lead, manganese, molybdenum, nickel, oxygen, scandium, selenium, silver, tellurium, tin, titanium, uranium, vanadium, zinc and zirconium.

The special advantages of the cathode-ray polarograph, in sensitivity and resolving power, will often allow for the simplification of existing methods, and have already been shown to make possible a number of determinations which are not possible in any other way.

The instrument consists of three standard 19 inch rack panels mounted in a strong metal box with fan cooling.

| | | |
|---|---|---|
| Dimensions: | 23 in. | (58 cms) wide |
| | 19 in. | (48 cms) deep |
| | 32 in. | (82 cms) high |
| Weight: | 160 lb. | (72·48 kg) |

The cathode-ray tube is mounted at a conventional viewing height, and the operating controls, which have been reduced to the minimum possible number are logically grouped and clearly designated.

The stand consists of a vertical member carrying the mercury reservoir and capillary tube, with provision for raising and lowering these as a unit and for adjusting the height of the reservoir relative to the capillary.

Incorporated in the box is a thermostatically controlled water-bath. This will accommodate three cells on a sliding carriage, enabling any one cell to be rapidly brought into position under the capillary. The bath is controlled to an accuracy of 0·25 °C over a range of 20 °C to 30 °C. Adequate control in a relatively high ambient temperature is obtained by making use of the mains water supply to enhance the rate of cooling and to provide stirring.

The cells, which are made of *Pyrex* glass, will accommodate from 1 to 5 cc. of solution and are provided with side arms for the anode connection and for bubbling with nitrogen. Three needle valves provide independent control of the gas flow in the cells.

# Annular chart recorder from Fielden

Fielden Electronics Ltd, have recently introduced a high-performance low-priced recorder known as the Servograph Mark II. This versatile instrument is suitable for direct operation from pH meters, $CO_2$ indicators, smoke density meters, beta gauges, tachometers and many other uses as well as a recording voltmeter and ammeter. The Servograph Mark II operates directly from micro-current sources; it can replace any moving coil indicating meter without imposing any additional load on the source of measurement or involving any loss of accuracy. One of the features of the new instrument is its unique principle of operation, which sets new standards in performance for graphic-recording meters. It is made in three models and is available for both laboratory and plant use.

*The Fielden Servograph Mk II has a variety of applications and will operate from any micro-current source*

# Corning "Multiform" glass now made in Britain

As a result of developments in glass technology originating in the United States, a new form of glass known as *Multiform* is now being produced for the first time in Britain, at the works of James A. Jobling & Co Ltd, of Sunderland, world-famous manufacturers of *Pyrex* heat-resisting glass.

In this process specially treated glass powders are compressed in moulds and subsequently fused to form a uniform opaque glass, destined in the main for the electronics industry, where high-precision glass parts are required for television tubes and mounting electrodes.

By the new method, the existing difficulty of making small and accurately dimensioned articles on long production runs is eliminated, for *Multiform* glass can be controlled to very fine limits.

Production at Joblings is being initially confined to television gun mount rods and to small beads which are being manufactured for glass-to-metal seals in order to speed up certain classes of production in the electronics field. At present, glass-to-metal sealing consists of moulding a glass bead on the inner conductor and then re-heating to seal to the outer metal. With *Multiform* processed beads of accurate dimensions, they can be preformed blanks for direct threading to the conducting wires.

# Mullard oscilloscope for pulse analysis

The Mullard L.140 is a new laboratory oscilloscope for the observation and accurate measurement of pulse waveforms. It has an especially linear triggered time-base with a large range of sweep durations, and a wide band Y amplifier. Signal delay is included so that the full wavefront of a random pulse may be displayed. The instrument is provided with stabilised power supplies, a cathode follower input probe, and a Mullard cathode ray tube with post-deflection acceleration.

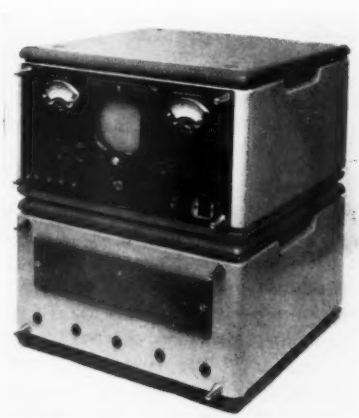
A new circuit has been developed which ensures time-base linearity, especially at the start of the sweep. This feature, together with the signal delay circuit, makes possible the accurate investigation of the complete leading edges of pulses.

Time base sweep durations are from 1 microsecond to 150 milliseconds, and a sweep expansion circuit continuously variable from 1 to 5 diameters can be used to expand the trace horizontally about the tube centre. When used in conjunction with the X shift controls, this allows minute examination of any part of the trace.

Triggering can be either internal (by the displayed waveform) or external (from a separate source of trigger voltage). With internal triggering, a sensitivity control allows sweep initiation at Y input levels corresponding to trace deflections down to 3 mm. Trigger sensitivity is independent of Y amplifier gain. Time measurement can be made with a maximum error of 3 per cent for time intervals from 1·5 microseconds to 150 milliseconds.

In the amplifier nine sensitivity settings ranging from 3mV/cm to 30V/cm are provided. The amplifier is directly coupled on the lower gain settings (100mV/cm and over), and has a rise time of 0·07 microseconds. On the high-gain settings a.c. coupling is employed, and the rise time is 0·08 microseconds. Pulse amplitude can be measured to better than 3 per cent (low gain 0·3-300V) or 4 per cent (high gain 10mV-1V).

The cathode follower probe has a high input impedance and gives an output which is linear to within 0·25 per cent for signal voltages from −150V to +150V. A backing-off voltage is provided, variable from −50V to +50V relative to earth potential.



*The L.140 instrument includes nine sensitivity ranges*

# BOOKS

**Electromagnetically Enriched Isotopes and Mass Spectrometry** Edited by *M. L. Smith*. 5·75 in. × 8·75 in. pp. XVI + 272. London 1956: Butterworths Scientific Publications, Price 45s

Even the man in the street today understands the value of radioactive isotopes, and particularly their use as tracers, but he probably does not know that the first examples of tracers were not radioactive at all. It is still true that there are a few elements for which no convenient radioactive isotope is available. In any case, the properties of the stable nuclides are of interest in themselves.

For all these reasons, many institutes have constructed apparatus for the separation of stable isotopes, and the present volume contains the papers and discussion at a symposium devoted to the electromagnetic (EM) method of separation, held at Harwell in September last. The EM method requires a source of ions, a magnetic field, electrical potential and a collector, and the first two groups of papers deal with the more difficult items, the ion source and the collection problem. There is a section on results in pure science achieved with stable isotopes, and one on measuring the relative amounts of different isotopes of one and the same element in a sample. (A mass spectrometer is, after all, but a small EM separator itself.)

The sixth section describes several complete installations which have been set up in the USA, UK, Denmark, France, Western Germany and Sweden; and the final section treats the problem of separating radioactive isotopes by the EM method.

The book is beautifully produced, with abundant photographs (not all of which are necessary) and is worth its price to the specialist, but not, I fear, to the general reader. *J. H. Awbery*

**Peaceful uses of Atomic Energy** Proceedings of the International Conference in Geneva, August 1955. New York 1956: United Nations. London 1956: Her Majesty's Stationery Office, PO Box 569, S.E.1, or from HMSO shops in London, Belfast, Birmingham, Bristol, Cardiff, Edinburgh and Manchester. 8·75 in. by 11·25 in.

Just a year ago the great United Nations conference opened in Geneva and if there were some who went there with scepticism in their steps there is no doubt at all that even after only a few sessions this was completely dispelled by events. It was in fact a unique experience and is likely to remain so. More, it was inspiring, and in the year that has passed it has become clear that it contributed an immense stimulus to our work in all countries.

To those who were not able to attend the conference, these volumes will come as something of a revelation: to those of us who were they still contain many surprises. For instance, about 500 papers were actually read at Geneva but no less than 1,050 were received: here they are all to be found. Furthermore, there is a complete record of the discussions on each session and these, in themselves, make fascinating reading.

The immediate reaction to this massive publication is inevitably one of distinct awe and a feeling that some kind of guide to it is necessary. With many nations working in secrecy for so many years, there is inevitably a considerable degree of duplication, if not on specific undertakings (for no one has built exactly the same kind of reactor), then certainly on fundamental research. This of course is no bad thing at the present state of development, but the miracle is that everything agrees so well. In the collation and comparison of all this accumulation of scientific data it is good to know that one British publisher has already started to publish a guide. Nevertheless for the serious worker in all the many fields of atomic energy, the appropriate volumes in this series are indispensable as source material.

The volumes are splendidly produced and their appearance (the first volume in English was published only about five months after the conference) must rank as a major publishing achievement.

Details of the 16 volumes are as follows:

| | | |
|---|---|---|
| Vol | 1 | The World's Requirements for Energy—the role of Nuclear Power. 57/- |
| Vol | 2 | Physics—Research Reactors. 57/- |
| Vol | 3 | Power Reactors. 54/- |
| Vol | 4 | Cross Sections Important to Reactor Design. 63/- |
| Vol | 5 | Physics of Reactor Design. 63/- |
| Vol | 6 | Geology of Uranium and Thorium. 63/- |
| Vol | 7 | Nuclear Chemistry and Effects of Irradiation. 70/- |
| Vol | 8 | Production Technology of the Materials used for Nuclear Energy. 70/- |
| Vol | 9 | Reactor Technology and Chemical Processing. 70/- |
| Vol | 10 | Radioactive Isotopes and Nuclear Radiations in Medicine. 57/- |
| Vol | 11 | Biological Effects of Radiation. 57/- |
| Vol | 12 | Radioactive Isotopes and Ionizing Radiations in Agriculture, Physiology and Biochemistry. 63/- |
| Vol | 13 | Legal, Administrative, Health and Safety Aspects of Large-scale Use of Nuclear Energy. 50/- |
| Vol | 14 | General Aspects of the Uses of Radioactive Isotopes—Dosimetry. 45/- |
| Vol | 15 | Applications of Radioactive Isotopes and Fission Products in Research and Industry. 54/- |
| Vol | 16 | Record of the Conference. 36/- |

The cost of a complete set is £46.0.0.

JOHNSON MATTHEY & CO LTD, 78 Hatton Garden, E.C.1, have recently issued a booklet—*Industry within an Industry*—extensively illustrated with photographs which describes the activities of the Company's five divisions, *i.e.* bullion, industrial, jewellery and allied trades, chemical and ceramic. Of particular interest to atomic energy are the company's products in rare and precious metals.

McGraw-Hill **new book**

# REACTOR SHIELDING DESIGN MANUAL

prepared by the United States Atomic Energy Commission
edited by Theodore Rockwell

*Technical Director, Naval Reactors Branch*
*Division of Reactor Development*
*US Atomic Energy Commission*

This book describes practical methods for designing, constructing and testing shields for reactor plants. The material has been prepared by research scientists of the Naval Reactors Branch, Division of Reactor Development, United States Atomic Energy Commission. It covers basic processes, setting allowable radiation levels, shielding the reactor core and the cooling system, shield engineering, the effect of irregularities in shield and the effect of geometry of radiation source.

The methods discussed have been used and tested in naval reactors and in the Shippingport Pressurized Water Reactor, the first large American reactor for utility power generation. They are based on practical experience, and take into account the problems of plant layout, structure and maintenance.

The basic approach simplifies the design of power reactor shields, since the lengthy and expensive reactor facilities needed for " mock ups " are not required. The information is presented in the order in which it will probably be used by the designer. A specially prepared index and separate tables of contents for each chapter add to the reference value of the book.

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UNITED NATIONS

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# Peaceful Uses of Atomic Energy

Publication has now been completed of the United Nations series—Peaceful Uses of Atomic Energy. The 16 volumes contain the only complete and official record of the International Conference on the Peaceful Uses of Atomic Energy — Geneva, 1955. All of the papers presented to the Conference are included as well as a record of the discussions.

I. The World's Requirements for Energy: The Rôle of Nuclear Power. 57s. (59s.)
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XV. Application of Radioactive Isotopes and Fission Products in Research and Industry. 54s. (55s. 9d.)
XVI. Record of the Conference. 36s. (37s. 6d.)

Prices in brackets include postage.

Brochures describing the volumes in detail are available on request.

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# PATENTS

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications may be obtained from the Patent Office (Sales Branch), 25 Southampton St, London, WC2, at 3s. 6d. a copy (including postage, inland and abroad)

## 729,613 ***Neutron source for well-logging apparatus*** *Schlumberger Well Surveying Corporation, May 11, 1955*

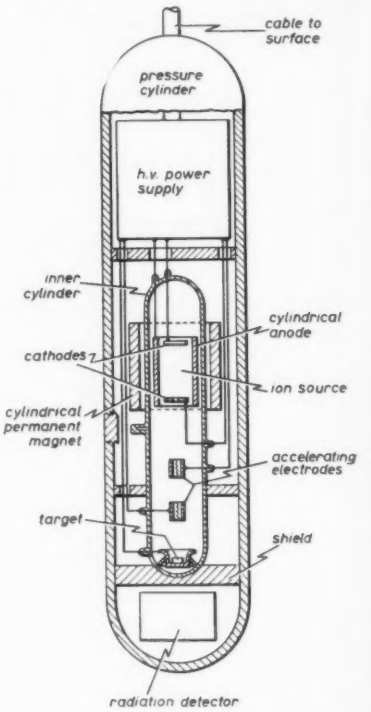
**The primary object of the invention is to provide a source of substantially mono-energetic neutrons which is sufficiently rugged to be passed through a borehole for logging subsurface formations. It consists of a miniature ion source, accelerator and target, the whole contained in a cylindrical pressure cylinder. This contains electronic equipment including a h.v. power supply, an inner cylinder containing the ion accelerating apparatus and a detector unit. The inner cylinder contains ionisable gas—preferably deuterium—at a pressure of the order of $10^{-4}$ mm Hg.**

**In operation, a free electron near the cathode of the ion source tends to accelerate towards the anode under the action of a positive potential of about 500 V, but the axial magnetic field deflects it and causes it to move in a tight helix towards the other plate. Here it is returned and the to-and-fro process is repeated. In this way a considerable path is obtained in a small space which gives the electron a chance to produce ions in the gas even although the mean free path is very long.**

**In the case of deuterium, the positive ions, or deuterons, now pass through the aperture of the lower plate to the accelerating electrodes. These may be one or several at progressively higher negative potentials. The final cathode is cup-shaped and may be at a potential of 20-100 kV below the aperture plate.**

**The target may be from one to several feet from the aperture cathode electrode and contains a substance which will produce neutrons when bombarded with the accelerated ions. For example, it may be a tungsten disk coated with zirconium impregnated with tritium. This reaction produces monoenergetic neutrons of 14 MeV. Another possible reaction is to use a deuterium target—here the neutrons will have energies of 2·5 MeV. The shield between the target and the radiation detector is intended to absorb the soft beta rays from the tritium decay.**

**In order to avoid depletion of the gas during a logging run due to it being progressively used up, it is desirable that the gas volume be as large as possible. The apparatus is intended to be used in accordance with the firm's methods of well-logging covered by British Patent 724,441.**




***D-T or D-D reactions can be used to produce neutrons***

## 752,152 ***Nuclear Reactor*** *Stichting voor Fundamenteel Onderzoek der Materie, Utrecht, Netherlands, July 4, 1956*

**In reactors moderated by heavy water, if the same liquid is used for cooling a drawback is encountered as the moderating qualities of heavy water are adversely affected by temperature.**

**It has been proposed to transport the heat generated by means of a separate liquid. If rods of uranium or uranium oxide are used, this may be done for example by suspending these rods, provided with a thin aluminium coating, in a circulating liquid, from which the heat may be recovered by pumping said liquid through a heat exchanger.**

**However, there remains the disadvantage that the moderator is not only heated by nuclear effects but also by the conduction of heat by the partition walls between the space for the moderator and the space in which high temperatures are produced by fission.**

**As is generally the case with materials employed within nuclear reactors, the partition walls should absorb the smallest possible amount of neutrons, for which reason they are made from a substance of low neutron absorption capacity, *e.g.*, aluminium, and are moreover made as thin as possible. The simultaneous requirement for high heat-insulating capacity, however, is not yet satisfied by the constructions hitherto proposed.**

**It has been found that walls with a good heat-insulating capacity can be obtained, without their neutron absorption capacity rising to inadmissible values, by coating, on the moderator side, with a porous material which in itself possesses only a low neutron absorption capacity. The cavities in this material will then get filled with heavy water, as a result of which a very good heat-insulation is obtained.**

**The porous material may consist, *e.g.*, of carbon or aluminium oxide, but it is preferred to use very loosely sintered beryllium oxide as the porous material.**

**It has appeared that if the partition wall between the reactor space proper and the moderator space is coated with a 1 cm thick layer of loosely sintered beryllium oxide, the amount of heat to be carried off by the moderator at a temperature drop of 250°C across the wall, is only 7 per cent of the heat produced in the reactor. As 5 per cent of this heat is generated in the moderator by nuclear effects, only 2 per cent is transmitted by thermal conduction through the wall.**

**If the partition wall proper is made of tightly sintered beryllium oxide, the reactor may be so constructed that an amount of plutonium comparable with the disappearing quantity of $U^{235}$, can be bred therein when using natural or only slightly enriched uranium as nuclear fuel. By preference the nuclear fuel is in this case applied in the form of a suspension in heavy water. Heavy water or beryllium oxide may be used as the reflector.**

**In order that the partition walls will not be unduly loaded without necessity and their thickness may consequently be kept small, the pressure difference across the wall is preferably kept below a given critical value. What pressure difference is still admissible depends on the nature of the partition wall and on the temperature difference to which this wall is exposed. Preferably the pressure difference is kept at practically zero, or the pressure on the moderator side is chosen slightly above that on the side of the reactor proper. This is especially advantageous in case the nuclear fuel is applied in the form of suspension in heavy water.**

# AUG 1959

XU

## John Thompson's £35M orders

The stainless steel vessel, primary heat exchanger units and ancillary equipment for the Dounreay fast breeder reactor (NUCLEAR POWER June) are now in the advanced stage of construction at the Ettingshall works of John Thompson Ltd and will shortly be ready for erection inside the containing sphere. This was stated by chairman Edward W. Thompson at his company's 21st AGM at the works on July 18th. Mr Thompson revealed that his company's share in the AEI–John Thompson Nuclear Energy Co Ltd was one-third and that it was now engaged in finalizing designs and preparing a tender for the first two CEA nuclear power stations. He added that these were very large projects costing between £15m and £25m.

Mr Thompson went on "It appears certain that nuclear energy will progress at an increasing pace, both in this country and abroad. It seems inevitable, however, that the international situation will have a big influence for some time to come, and in particular the availability of enriched fuel sets some limit to the directions in which we should seek for progress." Referring to his group's new centralized research laboratory, the Thompson chairman said it was already proving of value. "The cost," he continued, "is an additional expense but we feel we are compelled to keep in the forefront of new developments and that in the long run your company must benefit by our doing so."

The John Thompson group now has orders worth £35m. The year ended December 31, 1955, was one of development and further expansion—full results would not be seen immediately.

## Big turbine order for Parsons

Two 200 MW turbo alternators have been ordered from C. A. Parsons and Co Ltd of Newcastle on Tyne. One of these is for the Central Electricity Authority and the other is for the Hydro Electric Power Commission of Ontario.

The set for Canada will be the largest installed in the Dominion and it will be the first one of its size ever exported. The biggest machines so far ordered in this country are the 250 MW sets for the CEA station at High Marnham.

## Murex profits up—dividend held

According to preliminary figures, trading results from Sir Arthur Smout's Murex Ltd have again improved and group profits advanced from £1,025,000 to £1,245,000 for the year ended April 30th. A final dividend of 12½ per cent is being recommended, making 20 per cent for the year, less tax, on the £2.2m ordinary capital. The results reflect increased activities at Rainham and Waltham Cross and have enabled the company to absorb the major part of the rising costs, due mainly to increased salaries and wages. The meeting is on September 27th.

Murex Ltd are well known as suppliers of special metals used in nuclear energy and also as manufacturers of welding equipment.

## Ekco reactor controls for Australia

Over two-thirds of the production of Ekco Electronics Ltd is now being exported according to chairman E. K. Cole speaking at the Ekco group AGM in Westcliff-on-Sea on July 18th. Mr Cole said that sales to the British and overseas governments had been maintained and he paid tribute to the Ministry of Supply and the UKAEA for the cooperation his firm had received. He revealed that Ekco control equipment had been chosen for three of the first commercial atomic reactors—one of which is for Australia.

## Beckman Instruments

Baird and Tatlock (London) Ltd, Freshwater Road, Chadwell Heath, Essex, have been appointed agents for Beckman Instruments Inc, and are now equipped to deal with orders and provide a comprehensive service for Beckman spectrophotometers in this country.

A wide range of spectrophotometers and allied instruments are now available from the Beckman factory at Munich, Germany. As with other Beckman instruments these are imported directly from the United States subject to the necessary import licence being granted. Customers would assist the firm in making application for an import licence by stating the exact purpose for which the instrument is required. Baird and Tatlock Ltd have also announced that they have been appointed suppliers to the UKAEA.

## Anglo-American Computer Development

The British Tabulating Machine Co Ltd recently concluded arrangements with Laboratory for Electronics Inc of Boston, USA, for the joint establishment at Boston of a research and development company. This will carry out the design and development of a computer with certain novel features of particular interest in the business machine field. The first machine is for The Chase Manhattan Bank of New York, and the second will be delivered to The British Tabulating Machine Company immediately after.

The name of the new Company is International Computers Corporation Inc. The President will be a representative of The British Tabulating Machine Company Limited and the staff will include electronic engineers from both Companies, who have for some time been engaged on this project.

## K.D.G. now at Crawley

K.D.G. Instruments Ltd have now completed their move from Croydon to Manor Royal, Crawley, Sussex (Tel: Crawley 25151), after some twenty-five years in the Croydon area. The move has been necessitated through the very substantial increase in their range of instruments which in its turn has meant a large increase in production requirements.

The firm now offer a comprehensive range of indicating, controlling and recording instruments for liquid level and contents, pressure and temperature together with complete installation of instrument panels. New and improved methods of production layout and guaranteed cleanliness are features of the new factory.

## Solartron tackle US markets

On July 4th the first of a series of resident teams of Solartron Sales Engineers arrived at Los Angeles, USA. In three months' time it will be replaced by another team.

Mr I. H. Lynas, Solartron's chief instrument sales engineer, Mr J. Morrison, one of Solartron's senior technical service engineers and Mr G. Rigby, senior commercial research engineer, will establish a sales base on the West Coast. They will demonstrate Solartron equipment to potential users on this coast and will visit, during the course of their stay, San Francisco, Seattle, Chicago, San Diego, Salt Lake City, Portland (Oregon), Phoenix and Washington, DC. They will also organize the Solartron instruments exhibit at the Institution of Radio Engineers Show (Westcon) at Los Angeles from August 21st to 24th, and staff the Instrument Society of America's Exhibition at New York in the latter part of September.

In September 1955 The Solartron Electronic Group Ltd sent two teams for a month to explore the export possibilities for Solartron electronic instruments. It was found that some instruments were unique to the Americans and later successes at the Los Angeles and New York Exhibitions confirmed that the Solartron range of servo-testing instruments (essential for modern automatic controls and automation systems) were far in advance of present American development in this field.

It is intended to establish an American sales and servicing company in the near

future, to hold stocks at Philadelphia, Cleveland and Los Angeles, and to make nation - wide servicing arrangements through suitable agents. The team's West Coast headquarters will be at Messrs Western Instruments, Inc, Burbank, near Los Angeles, California, USA.

## Efco-Edwards Vacuum Metallurgy

The formation of a new company under the above name is jointly announced by Edwards High Vacuum Limited of Manor Royal, Crawley, Sussex, and the Electric Furnace Company Limited of Queens Road, Weybridge, Surrey. These two companies are leading specialists in high vacuum equipment and electric furnace installations respectively and have, for some time, been working together on vacuum metallurgical problems.

The first products of Efco-Edwards are a range of vacuum melting and pouring furnaces designed for research and production, as well as other standard plant for sintering, brazing, annealing and degassing metals. The policy of the new company, like both parent organizations, is one of constant research and development and larger non-standard furnaces are already on the drawing boards.

Typical examples of the increased demands made by engineers for metals with improved qualities are to be found in the modern aircraft industry and the rapidly growing atomic energy field. High physical qualities in the special alloys used for aircraft engines and other high duty units without increase in weight or volume can be obtained by producing these materials under vacuum, while atomic energy workers using rare metals for reactors already employ vacuum metallurgy on a large scale for processing. Improved characteristics can be given to many well-known metals and alloys by treatment under vacuum and America and Germany, in particular, have proved beyond doubt that there is an important future for this type of plant which has developed beyond the experimental and research stage to production units.

## Acheson honoured in Germany

The life and work of Dr Edward G. Acheson formed the subject of a lecture by Professor Robert Meldau at the Technische Höchschule, Hannover, on June 12th. Dr Meldau, who is a well-known authority on powder science in Germany, dealt with the results of Acheson's discoveries at the close of the nineteenth and opening of the twentieth century, this being the centenary of the birth of the discoverer of industrial methods of making pure graphite in the electric furnace and silicon carbide. The speaker dealt also with Acheson's valuable contribution to industry when he developed the first colloidal dispersions of graphite, "Aquadag" and "Oildag." The lecture was illustrated by many new electron microscope studies.

After the lecture a Centennial dinner was attended by a number of German scientists, including Professor Dr D'Ans and Professor Augustin of Berlin Technical University, Dr Schonfeld, Rector of Hannover Technische Höchschule being the guest of honour. Professor Hinspetter and Professor Kiensle were also present, while Mr E. A Smith, Technical Manager of Acheson Colloids Limited, of London, attended on behalf of the units of the Acheson organization.

## Spanish visitors at John Thompson

A Spanish Government delegation was in England recently as guests of the Board of Trade, to study the development of nuclear energy, on a programme arranged by the AEA. During its visit to the Midlands on July 19th, the delegation visited the works of the John Thompson Group at Ettingshall, Wolverhampton.

The visitors were met by Mr Edward Thompson, chairman and managing director and Mr J. H. N. Thompson, deputy chairman and joint managing director.

His Excellency Señor Don Juan Antonio Suanzes Fernandez, president of the Instituto Nacionale de Industria and Sr de Gaztelu, chief electrical engineer headed the visiting party. They were accompanied by Sr Dargent, director of the Instituto Nacionale, Sr Martinez, Sr Gimenez-Arneu, economic councillor of the Spanish Embassy, London and Mr T. F. J. Lattimer of the Board of Trade.

After inspecting the new John Thompson Group research laboratories the visitors were shown a model of Britain's first full-scale fast breeder nuclear reactor, which is now under contract at Dounreay, Caithness. During an extensive tour of the factories the delegates were shown the fabricated stainless steel primary heat exchangers and the complex central stainless steel reactor vessel.

At specific points of the tour the party was met by Mr R. D. Edwards, works manager and director of John Thompson (Pipework) Limited, Mr A. C. Coleman, works manager and director of John Thompson (Wolverhampton) Limited, and Mr S. H. Griffiths, head of the John Thompson Group Research Laboratories.

Visits to the UKAEA establishments were also included in the Spanish visitors' itinerary.

## Dividends maintained at Aiton

A final dividend of 12½ per cent to make 20 per cent less tax for the year ended March 13th was recommended recently by the directors of Aiton and Co Ltd of Derby. This is unchanged over the previous year although the distribution was covered over eight times. According to chairman Wing Cdr J. M. Aiton, the net profit was up from £250,314 to £200,326 and the total volume of orders in hand and being received was very satisfactory.

Aiton are well-known as pipework contractors for many British thermal power stations and have supplied pipework for the Calder Hall nuclear power station.

# NAMES IN THE NEWS

**Mr H. G. Nelson,** deputy managing director of the English Electric Company has been appointed managing director. **Sir George Nelson,** chairman and managing director has relinquished the post of managing director in order to devote himself full-time to the duties of executive chairman of English Electric.

**Sir Jack Stevens,** it was recently announced, is resigning from the chairmanship of the Australian Atomic Energy Commission in order to take up a post with a private firm in September.

**Mr G. E. Condliffe** has relinquished the post of Managing Director of E.M.I. Research Laboratories Ltd, to become Research and Technical Consultant to the Chairman and the Managing Director of Electric and Musical Industries Ltd. **Mr Clifford Metcalfe** has been appointed Managing Director of E.M.I. Electronics Ltd.

**Mr A. H. Giles** has joined Heat Transfer Ltd, as Managing Director. Mr. Giles was formerly with Heat Exchangers Ltd and Superheater Co Ltd.

**Mr Harry West** has been appointed managing director of AEI-John Thompson Nuclear Energy Co Ltd.

**Mr Norman Baker** is to join the board of Taylor Woodrow Construction Ltd. He joined the company in 1946 and was promoted chief estimator in 1953.

**Air Chief-Marshal Sir Ralph Cochran** has joined Rolls-Royce Ltd, as head of its nuclear energy project. Sir Ralph, who was one of the men behind the dambuster raids, retired from the RAF as Vice-Chief of Air Staff in 1952.

## Distinguished lecturers at Borough Poly

A course of twenty-four lectures on nuclear power is to be given at Borough Polytechnic, Borough Road, London, SE1, commencing on Thursday October 11. There will be two series; one at 4 pm and another at 7 pm. Each lecture will be followed by a discussion. The lecturers will be: A. J. L. Collinson, senior lecturer in nuclear physics, Borough Polytechnic; Dr J. V. Dunworth, Harwell; Mr B. L. Goodlet, Brush Electrical Engineering Co Ltd; J. R. Hamson, Harwell; R. K. Hilton, General Electric Co Ltd; D. J. Littler, Harwell; G. E. Preece, de Havilland Engine Co Ltd; I. Wilson, Harwell; and D. V. Wordsworth, Harwell. The fee for the course is £2 10s, and applicants should possess a knowledge of mathematics at least to the level of the Higher National Certificate in Electrical Engineering.

## Instrumentation show for London

An exhibition—*Instruments, Electronics and Automation*—will be held at Olympia, London from May 7-17 1957. The show is being sponsored by five trade associations: British Electrical and Allied Manufacturers Associations, British Industrial Measuring and Control Apparatus Manufacturers Association, British Lamp-blown Scientific Glassware Manufacturers' Association, Drawing Office Materials Manufacturers and Dealers Association and the Scientific Instrument Manufacturers' Association of Great Britain. The chairman of the joint Exhibition Committee is Mr L. S. Yoxall, chairman and managing director of Foxboro Yoxall Ltd and the secretary is Mr E. D. Hart.

The exhibition, which will take the place of the instrument section of the British Industries Fair, will cover the complete field of laboratory and industrial instrumentation and during its run there will be a continuous programme of conferences, lectures and meetings.

Full particulars of participation may be obtained from Mr T. E. Rees, Industrial Exhibitions Ltd, 105-106 New Bond Street, London W.1, Telephone HYDe Park 9583. Closing date for space bookings is October 1st.

## Nuclear studies at Wolverhampton

A short course of ten lectures—*Introductory course in Nuclear Engineering*—is to be held at the Wolverhampton and Staffordshire Technical College, Wulfruna Street, Wolverhampton, commencing on October 5th. This course is primarily for engineers requiring a fundamental knowledge of nuclear energy as applied to power generation and will be followed by a more advanced course—*Nuclear Engineering*—which is due to begin in January 1957. Specialist lecturers have been engaged. Enrolment forms will be available in September and meanwhile the Head of the Department of Mechanical Engineering would welcome preliminary enquiries from interested firms and individuals.

## New President for SIMA

At the Annual General Meeting of the Scientific Instrument Manufacturers' Association on July 12, the retiring President, Mr C. E. T. Cridland, installed his successor, Mr G. A. Whipple in the Chair for the year 1956-57.

Other officers were elected as follows:
Vice President: Mr P. Goudime, Electronic Instruments Ltd.
Hon. Secretary: Mr J. E. C. Bailey, CBE, Baird & Tatlock (London) Ltd.
Hon. Treasurer: Mr Chas. H. Warner, W. F. Stanley & Co Ltd.

New members of Council taking office at the same time were:
Mr F. W. Dawe, Dawe Instruments Ltd.
Mr P. J. Ellis, OBE, R. B. Pullin & Co Ltd.
Mr J. M. Furnival, MBE, Marconi Instruments Ltd.
Mr D. F. Newstead, Rank Precision Industries Ltd, Kershaw Division.
Mr J. A. Stafford, Taylor, Taylor & Hobson Ltd.
Mr W. H. Storey, Unicam Instruments Ltd.
Mr N. Trepte, Griffin & George Ltd.

Members of Council who retired from office under the rules of the Association are:
Mr A. W. Smith—Vice President, Wray (Optical Works) Ltd.
Mr S. Borthwick—Hon. Treasure, R. & J. Beck Ltd.
Mr T. Bennett, W. Watson & Sons Ltd.
Mr R. Broadbent, Sperry Gyroscope Co Ltd.
Mr A. Ridding, Ferranti Ltd.
Mr E. E. Snow, U.K. Optical Bausch & Lomb Ltd.

Mr G. A. Whipple, MA, MIEE, FInstP, Chairman and Managing Director of Hilger & Watts Ltd, has been associated with the scientific instrument industry all his life and has strong family connections. His father was chairman of the Cambridge Instrument Company, and president of SIMA on seven occasions, furthermore several generations of the family have been Superintendents at Kew Observatory. He was educated at Gresham's School and Trinity College, Cambridge, and after two years' experience with both British and German firms joined the Cambridge Instrument Co, where he was for eight years, mainly on high speed cathode-ray oscillograph research.

In 1939 he became a director of E. R. Watts & Son Ltd, being appointed Managing Director on the death of Mr Frank Watts. In 1945 he became Managing Director of Adam Hilger Ltd, and when the amalgamated firm of Hilger & Watts Ltd, was formed in 1948 he was appointed Chairman and Managing Director.

Mr Whipple is well known for his many activities in connection with scientific instruments and engineering and is a past member of Council of the Institution of Electrical Engineers. He has concerned himself particularly with technical education and training and is, amongst other similar positions, a member of the Governing Body of the National College of Horology and Instrument Technology.

## BA at Sheffield

The 118th meeting of the British Association for the Advancement of Science is to be held in Sheffield from August 29th to September 5th under the Presidency of Sir Raymond Priestley. In Section A—Mathematics and Physics—Prof H. S. W. Massey will lecture on *The discovery and significance of the anti-proton*, while Mr L. Rotherham of the AEA's Industrial Group, Risley, will speak on *The Metallurgy of atomic energy*.

In Section B—Chemistry—Prof George Porter will talk about *Very high temperature reactions*, while in Section G—Engineering — Dr Denis Taylor, Electronics chief at Harwell, will lecture on *Atomic energy and automation*.

## New Chair at London University

The University of London has announced the appointment of Dr J. M. Kay to the newly-instituted Chair of Nuclear Power at the Imperial College. This will provide a focus in the College for study and interest in the fundamentals of nuclear power and in the engineering techniques involved. It will operate through postgraduate courses and research, and will maintain close liaison with all the departments of Engineering and with those of Physics and Chemistry. Dr Kay is 35; he graduated at Cambridge University, where he later held a University Demonstratorship in Chemical Engineering. In 1952 he was appointed Chief Technical Engineer at the Department of Atomic Energy's Industrial Group Headquarters at Risley, Lancashire. Since 1955 he has acted as a consultant in the field of nuclear power and in related industries.

# RESEARCH REPORTS

## United Kingdom

*The following reports have recently been made available to the public by the United Kingdom Atomic Energy Authority. They may be borrowed or photocopies obtained from the following libraries: British Museum; University Library, Cambridge, Radcliffe Science Library, Oxford; National Library of Scotland, Edinburgh; Patent Office Library, London; Science Museum Library, London; Mitchell Library, Glasgow; and the Central Libraries at Birmingham, Liverpool, Manchester, Newcastle-upon-Tyne and Sheffield.*

### Atomic Energy Research Establishment

**A comparative study of three recently developed polarographs.** D. J. Ferrett, G. W. C. Milner, H. I. Shalgosky, L. J. Slee. (Feb 1956. 19 pp) AERE-C/R 1864

**The preparation of uranium trioxide by thermal decomposition of uranyl nitrate.** B. A. J. Lister, R. J. Richardson. (Jan 1956. 15 pp) AERE-C/R 1874

**Further electron guns for use in metre-wave high power triodes.** L. S. Holmes. (Jan 1956. 19 pp) AERE-GP/M 187

**Inhibition of liquid-metal corrosion.** J. W. Taylor (Feb 1956. 9 pp) AERE-M/TN 35

**The atomic energy power programme.** A selected reading list. (Mar 1956. 4 pp) AERE-Inf/Bib. 97

**The industrial uses of isotopes.** A selected reading list. (Mar 1956. 6 pp) AERE-Inf/Bib. 98

**A general introduction to nuclear engineering.** A selected reading list. (Mar 1956. 2 pp) AERE-Inf/Bib. 99

### Industrial Group

**The determination of alpha and beta activities in mussels and other invertebrates.** Chemical Services Dept. Windscale. (Apr 1956. 2 pp) IGO-AM/W 34

**The determination of alpha and beta activities in vegetation, roots, seaweed, soil, seabed sludge, seashore sand, silt, and river mud.** Chemical Services Dept. Windscale. (Apr 1956. 4 pp) IGO-AM/W 35

**The determination of alpha and beta activity in fish.** Chemical Services Dept. Windscale. (Apr 1956. 3 pp) IGO-AM/W 36

**Counting the total alpha activity of granular material at 'infinite depth' using an alpha scintillation counter type 1093.** Chemical Services Dept. Windscale. (Apr 1956. 4 pp) IGO-AM/W 37

**The conversion of an M.S.1 and M.S.2 for the isotopic analysis of lithium.** J. Bishop, P. G. Bentley. (Feb 1956. 35 pp) IGR-R/CA 164

**The effect of a variable heat flux on the heat transfer co-efficient.** T. Burgoyne. (Mar 1956. 18 pp) IGR-TN/W 306

## Canada

*The following reports may be obtained from: Scientific Document Distribution office, Atomic Energy of Canada Limited, Chalk River, Ontario. Remittances should accompany the order and should be in the form of cash, bank or express postal money orders or cheques made payable in Canadian funds at par in Chalk River to Atomic Energy of Canada Limited.*

**Liquid-liquid extraction under conditions of concentration equilibrium.** S. D. Cavers. 1952. 92 pp) $1.00. AECL 60. CEI-52

**Proportional neutron counters.** B. H. Flowers. (1946. 17 pp) 25c. AECL 62, CRP-292

**Thermal utilization in a system containing two moderators.** E. A. Guggenheim. (1946. 10 pp) 25c. AECL 63, MT-220

**Aerial prospecting for radioactive deposits in snowfalls.** E. A. Godby, G. S. Levy, H. Carmichael. G. Cowper, J. F. Steljes. (1951. 37 pp) 50c. AECL 64, MR-16

**Heat transfer experiments with special reference to the thermal resistance of anodized layers.** S. G. Bauer, P. M. Milner. (1945. 15 pp) 25c. AECL 111, MTec-143

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**Some economic aspects of nuclear fuel cycles.** W. B. Lewis. (30 pp) 50c. AECL 203

**Experiments on some characteristics of the NRX reactor. Part I—methods and prolonged fuel irradiation.** D. G. Hurst. (20 pp) 25c. AECL 204

**Experiments on some characteristics of the NRX reactor. Part II—temperature and transient poison effects.** A. G. Ward. (22 pp) 50c. AECL 205

**Experience with heavy water systems in the NRX reactor.** R. F. S. Robertson. (12 pp) 25c. AECL 206

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*The more important reports of the United States Atomic Energy Commission are published by the Office of Technical Services, US Department of Commerce, Washington 25, DC. Others of a more specialised nature are deposited at the Library of Congress. The OTS reports are printed and may be ordered from the address given. Those at the Library of Congress (LC) are available only on microfilm (Mi) or photocopy (ph). Orders for these reports should be sent to: Library of Congress, Photoduplication Service, Publications Board Project, Washington 25, DC. The reports listed here are only a very small selection: the full list is given in the monthly publication* US Government Research Reports *which is obtainable from the OTS at an annual subscription of $9.*

**Isothermal pump loop.** R. Keen. North American Aviation, Inc, Downey, Calif. (Oct 1952) Decl Dec 1955. Contract AT-11-1-gen-8. 10 pp. Order from LC. Mi $2.40, ph $3.30. AECD-3831

**Flash cooling of primary cooling water.** J. J. Byrnes and K. Diehl. Ferguson (H.K.) Co, NY. Jan 1952, Decl Dec 1955. 11 pp. Order from LC. Mi $2.40, ph $3.30. AECD-3902

**Selection of engineering materials for low thermal neutron absorption properties.** J. E. Mahlmeister, D. H. Inhoff and J. P. Frankel, California Research and Development Co, Livermore, Calif. Sept 1951, Decl Dec 1955. 16 pp. Order from LC. Mi $2.40, ph $3.30. AECD-3948

**Package power reactor no. 1 — primary coolant system calculations.** W. R. Gall. Oak Ridge National Lab, Oak Ridge, Tenn. Apr 1953. Decl Nov 1955. 29 pp. Order from OTS. 25 c. AECD-4210

**Quarter-point gas introduction scheme for helium cooled plant.** M. C. Leverett, Clinton Labs, Oak Ridge, Tenn. Oct 1952. Decl Dec 1955. 9 pp. Order from LC. Mi $1.80, ph $1.80. CE-288

**Cooling of the graphite reflector for the materials testing reactor.** R. B. Briggs, Oak Ridge National Lab, Tenn. Mar 1950. Decl Dec 1955. Contract W-7405-eng-26. Order from LC. Mi $3.60, ph $9.30. CF-50-3-102

**A description of two motor-operated valves and a special valve packing.** J. W. Anderson, W. C. Hazen, R. L. Thomas, and W. D. McNeese, Los Alamos Scientific Lab, Los Alamos, N. Mex. Sept 1953. Decl Dec 1955. Contract W-7405-eng-36. 18pp. Order from OTS. 20c. LA-1607

**An idea for a wide range neutron flux monitor for high flux reactors.** J. T. Russel, Hanford Atomic Products Operation, Richland, Wash. Mar 1954. Decl Jan 1956. Contract W-31-109-eng-52. 9 pp. Order from LC. Mi $1.80, ph $1.80. HW-31200

**Magnetic induction flowmeter development, project status report for July 1, 1951-June 30, 1952. Job 24-B4. Vitro Corp. of America, NY. Jun 1953. Decl Jan 1956.** Contract AT(30-1)-850. 62 pp. Order from LC. Mi $3.90, ph $10.80. KLX-1390

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